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FIELD PERFORMANCE OF POROUS FRICTION SURFACE COURSE

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16. Abstract

This report presents the results of a field performance survey first described in Report No. FAA-RD-73-197. Additional prototype construction experience and validation of a design procedure including a desired mixing viscosity range are reported. Long-term porous friction course (PFC) performance is recorded and combined with laboratory test results that provide data for a new recommended PFC gradation, water permeability requirements, and initial voids total mix requirement.

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PREFACE

This project was conducted by the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the Federal Aviation Administration as a part of Inter-Agency Agreement No. DOT FA71WAI-218.

The project was conducted under the general supervision of Mr. James P. Sale, Chief of the Soils and Pavements Laboratory. This report was written by Mr. Thomas D. White and covers work done from December 1971–June 1975.

COL G. H. Hilt, CE, was Director of WES during the preparation of this report. Technical Director was Mr. F. R. Brown.

TABLE OF CONTENTS

METRIC CONVERSION FACTORS

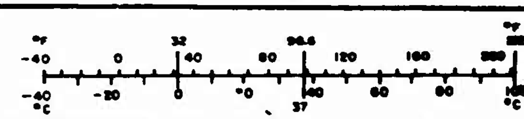
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

The overall objectives of the porous friction surface course (PFC) study were to develop a PFC mix design method and construction specifications. To accomplish these objectives, a program was followed that included a review of pertinent literature, design methods, and construction specifications; observation of PFC construction; laboratory study of PFC mix design methods; and field inspection and evaluation of PFC performance.

The review of literature and current PFC construction experience indicated that PFC job-mix formulas have been adopted largely based on subjective evaluations of tests. The laboratory portion of the PFC study was therefore directed at identifying a physical property that would correlate with PFC field performance. Results of these tests indicated a lack of sensitivity of PFC mixes to physical test methods. Positive results of the laboratory work included development of a laboratory water permeability test and adaptation of the laboratory test equipment to field testing. A minimum water permeability of 1000 ml/min was recommended. A method for determining density of PFC and other open-graded mixtures was recommended as well as a procedure for preparing PFC samples comparable with actual in-place PFC pavement surfaces.

Observations of several PFC construction jobs provided information for preparing a standard specification for PFC. The PFC specification was written early in the project, but very few changes have been recommended.

Continued laboratory studies and evaluation testing of field samples provided data for analysis and development of a mix design concept. Correlation of laboratory test results and field performance indicated that an estimate of the asphalt content (EOA) could be made from the relation $EOA = 2K_c + 4.0$, where K_c is the coarse aggregate fraction surface area constant as determined by the California Centrifuge Kerosene Equivalency (CKE) test, Test Method California No. 303F. Construction experience indicated a need for selecting a rational mixing temperature to reduce asphalt drainage problems during construction. Job

asphalt temperature-viscosity data were analyzed with field observations of asphalt drainage, and a preliminary mixing viscosity of 450 centistokes was adopted to reduce this problem. Subsequently, field testing on PFC construction indicated that a mixing viscosity of 275 $\pm$ 25 centistokes could be used.

Attempts to measure water permeability in the laboratory and in the field led to the development of a portable permeability device. PFC water permeability was used to select the geometry of specimens and compaction effort by which to prepare laboratory specimens. In addition, permeability was used to evaluate gradations for desirable permeability properties. The results of these evaluations were used to modify the recommended PFC gradation.

Several conclusions were drawn from the PFC field and laboratory performance evaluations: (a) PFC should only be considered for application to structurally sound pavements; (b) the aggregate Los Angeles abrasion requirement of 25 is satisfactory; (c) medium to soft paving grades of asphalt can be used satisfactorily at the volumes of asphalt determined by the PFC mix design procedure; (d) neoprene rubberized asphalts are good binders for PFC; and (e) raveling stabilizes in 12 to 18 months, even with low binder content and soft asphalts. No problems developed from freezing and thawing cycles, but a future problem may develop where heavy buildup of rubber occurs.

INTRODUCTION

BACKGROUND

This report presents the evaluation of performance of porous friction course (PFC) for airport pavements. Results of the initial literature and laboratory studies and preliminary field evaluation are presented in Report No. FAA-RD-73-197, "Porous Friction Surface Course."[1]

In the latter part of 1971 and in 1972, a number of airfield PFC's were constructed. These PFC's were located in different climatic areas of the United States. They were constructed using a range of binder materials, aggregate types, and gradations, and they were subjected to a wide range of traffic types and levels.

An extended performance evaluation was not originally planned for this project, but results of laboratory tests and preliminary field observations indicated a need for this type of study.

OBJECTIVE

The objective of this report is to present validation data on the design, construction, and performance of PFC pavements.

SCOPE

Additional data on design and construction were obtained from participation in the design and construction of a new PFC for a runway at the Greensboro--High Point--Winston-Salem Airport in North Carolina. The performance data on PFC pavements were collected through a series of condition surveys on 10 airports that have PFC pavements, including the pavements surveyed for the earlier report.[1] Table 1 lists the locations of the 10 pavements surveyed.

NEW CONSTRUCTION

During September 1974, a PFC pavement with a neoprene rubberized asphalt binder was constructed at the Greensboro--High Point--Winston-Salem Airport. Participating in the planning and construction of the pavement were the Federal Aviation Administration (FAA) district and regional offices in Atlanta; the Greensboro--High Point--Winston-Salem Airport Authority; and the U. S. Army Engineer Waterways Experiment Station (WES).

Samples of the aggregate stockpiles proposed for the job were shipped to WES, and a PFC mix was designed using the procedures proposed in the conclusions and recommendations of the initial report.[1] The aggregate physical properties are shown in Table 2.

The recommended laboratory job-mix formula consisted of the following:

Gradation

Sieve Size	Percent Passing
1/2 in.*	100
3/8 in.	95
No. 4	37
No. 8	20
No. 30	8
No. 200	3

Binder content .... 6.5 percent by weight

Mixing temperature ... 280°F

* A table of factors for converting U. S. customary units of measurement to metric units is presented on page 5.

The temperature-viscosity relation for this binder, a neoprene-modified asphalt, is shown in Figure 1. The mixing temperature was selected at a viscosity of 450 centistokes. Experience has indicated that this is a safe viscosity and allows good aggregate control to be established without problems of excess asphalt (binder) drainage.

A safe viscosity (temperature) is considered to be one at which excess asphalt drainage in the PFC will not occur. At a given viscosity, an asphalt will coat a constant aggregate surface area with a certain film thickness. If there is a volume of asphalt in the mix in excess of that required for aggregate coating, asphalt drainage will occur. In addition, even though the optimum asphalt content is proportioned into the mix, an increase in mixing temperature will cause a corresponding decrease in viscosity, and the asphalt will become more fluid. As a result, a thinner film of asphalt will coat a constant aggregate surface area. The amount of asphalt in excess of that needed to form the aggregate coating will drain and cause rich spots in the pavement. Even though the optimum asphalt content is added at the desired viscosity, poor gradation control will cause the aggregate surface area to vary. If the aggregate surface area is too low, the resulting excess asphalt will also cause drainage.

Field analysis of stockpiles at Greensboro indicated a variance in gradations from those furnished for the laboratory mix design, particularly with respect to the coarse aggregate. Because of nonuniformity of the aggregate stockpiles, a new coarse aggregate with a gradation nearer that of the original coarse aggregate was obtained. With the new material, a field job-mix formula was established consisting of the following:

Gradation

Sieve Size	Percent Passing
1/2 in.	100
3/8 in.	97 ± 3
No. 4	38 ± 3
No. 8	15.7 ± 2
No. 30	6.1 ± 2
No. 200	2.0 ± 1

Binder content .... 6.5 ± 0.25 percent by weight

Mixing temperature ... 280 ± 6°F

No change in asphalt content was recommended since the same aggregate type was being used and there were minimal differences in gradation. The gradation was recommended with consideration to the need to use the

available aggregates and to maintain a high voids content in the mix. The uniformity of the new coarse aggregate provided a gradation well within the job-mix requirements.

A prior agreement with the FAA and the Airport Authority was made to allow WES to vary both the mixing temperature and binder content to obtain information to validate the recommended design procedure. The following tabulation presents the results of the observations:

Binder Content percent	Mixing Temperature °F	Comments
6.5	280	No bleeding
6.5	300	Smoother laydown than at 280°F
6.5	320	Bleeding in laydown machine hopper
6.5	300	No bleeding
6.75	300	No bleeding
7.0	300	Loss of mix consistency; individual aggregate could be separated from mix

The temperature variation study was conducted to define a mixing temperature compatible with the binder content determined from the design procedure. Experience has shown that the binder content determined by the design procedure results in good field performance. The study was made to observe the mix during mixing, hauling, and placement. Because of difficulty in performing extraction tests on PFC, scale weights were observed during batching to insure that the desired amount of asphalt was proportioned into the mix.

Based on the above observations, the final field-adjusted mix consisted of the aggregate gradation shown on page 10 combined with 6.5 binder at a mixing temperature of 300°F.

Figure 2 shows the mix as it was being loaded into the laydown machine hopper. A compacted edge and the surface texture are shown in Figure 3. The overall surface texture and appearance are shown in Figure 4.

FIELD SURVEYS

Condition surveys were conducted on PFC pavements at nine airports throughout the United States. These are the pavements described in the original PFC report.[1] Tables 1 and 2 present an updated summary of the dates and types of surveys conducted and the construction data. Results of surveys conducted in 1973, 1974, and 1975 are presented in Tables 3, 4, and 5. The results of laboratory tests on samples collected in 1973 are included later in this report

Skid resistance tests using the British Portable Skid Resistance Tester described in American Society for Testing and Materials Designation: E 303-69[2] and water permeability tests using procedures described in Appendix A were conducted on the in-place pavement. Samples (6-in.-diam cores) of the PFC were removed from the pavement both in and out of traffic areas for laboratory testing. Method 101 of Military Standard MIL-STD-620[3] was used to determine density and voids using values for the volume of the samples determined from physical measurements.

PEASE AFB

During the survey conducted in September 1974, reflective cracking that had been noted in previous visits was still evident (Figure 5). At this time, there was a series of reflected cracks approximately 7 ft to the south of the runway center line, intermittently along the length of the runway (Figure 6). Petroset was used to seal these reflected cracks. Some raveling was still occurring as well as some damage due to locked-wheel turns and jet blast (Figure 7). No significant snow removal equipment damage was noted. Urea is used in snow and ice removal operations at Pease AFB, and it was reported that more urea is required for the PFC surface. There has been some rubber buildup, but it is not considered a problem (Figure 8). Base personnel indicated that they were satisfied with the PFC's performance.

In March 1975, Pease AFB was visited again and a visual inspection of the PFC conducted. Also, 6-in.-diam cores were removed from the pavement for further laboratory analysis. No significant change in the

condition of the PFC was noted. However, during coring operations, it was observed that the PFC was not bonded to the underlying pavement outside the traffic areas. Two possible causes for this are the weather, which at the time of the coring was cold, and the low binder content used in construction, which may have resulted in poor adhesion to the underlying pavement. Better adhesion in traffic areas would be expected due to the compaction effort.

HOT SPRINGS AIRPORT

In September 1974, a survey indicated that the overall condition of the PFC pavement was good. There was no reflective cracking or raveling; however, there were some minor scars caused by snow removal equipment (Figure 9) and there was some scuffing due to locked-wheel turns by aircraft (Figure 10). Lock-wheeled turns are made at Hot Springs because there is no parallel taxiway. The airport manager was very satisfied with the PFC's performance. He stated that the PFC did not seem to freeze as fast as dense surface course pavements, but once frozen, it did not thaw as fast.

In March 1975, Hot Springs Airport was again visited and a visual inspection of the PFC conducted. Six-in.-diam cores were removed from the pavement for laboratory analysis. The condition of the pavement was good. No problems have occurred with this pavement other than the minor damage caused by locked-wheel turns.

NASHVILLE METROPOLITAN AIRPORT

A survey of the Nashville Metropolitan Airport was made in September 1974. In the traffic areas, there was rutting of the pavement. Cores of the PFC showed that the significant consolidation was confined to the PFC layers. Figure 11 shows water from coring operations running down a rut. Figure 12 shows excess asphalt and deposited rubber that were marked by the tread of an aircraft tire.

As previously described,[1] the PFC was placed on a 1000-ft section of pavement in a touchdown area. The traffic in this area caused a buildup of rubber, which, combined with the densification, resulted in an

impermeable surface. Outside the traffic areas, the permeability of the PFC was adequate. Nashville Airport engineering personnel voiced dissatisfaction with the performance of the PFC at the time field inspections were conducted.

In March 1975, Nashville Metropolitan Airport was visited to visually inspect the PFC and obtain samples for laboratory testing. The problems of consolidation, rutting, and rubber buildup were continuing (Figures 13, 14, and 15). Continued dissatisfaction with the PFC was voiced by airport engineering personnel. Plans are being made to overlay the entire runway with portland cement concrete.

NAVAL AIR STATION, DALLAS

A field party visited the Naval Air Station, Dallas, in November 1973 and conducted field tests and collected samples for laboratory testing. At that time, Public Works Office personnel expressed their satisfaction with the PFC. The overall condition of the PFC was good, and good drainage was observed in the area where jet blast damage had occurred (Figure 16). Previously reported raveling problems seemed to be stabilized. However, a few areas near the south end of the runway were still raveling (Figure 17). Some gouging from aircraft arrester hooks was observed (Figure 18). Both transverse and longitudinal reflected cracks were observed (Figure 19). No significant increase had occurred in raveling at those reflected cracks that were observed in the previous survey.

In April 1975, Dallas was visited to visually inspect the condition of the PFC and remove 6-in.-diam samples from the pavement for laboratory testing. No change in the PFC's condition or performance was noted.

KIRTLAND AFB (KAFB)

As noted in the report of field observations in May 1973,[1] the PFC test sections at KAFB received only minor traffic. Therefore, as expected, the condition of the PFC test sections was relatively unchanged when a field party visited KAFB in October 1974 to conduct field tests and collect samples for laboratory tests. The only change observed was

that there seemed to be some stripping of the asphalt. The raveling of aggregate reported previously was continuing.

A field party visited KAFB again in April 1975 to make a visual inspection and remove 6-in.-diam samples from the pavement for laboratory testing. The condition of the pavement remained relatively unchanged except for continuation of the raveling problem.

GREAT FALLS INTERNATIONAL AIRPORT

An account of a visual evaluation in May 1973 of the PFC at Great Falls International Airport is presented in Reference 1.

In October 1974, a field party visited the airport to conduct field tests and collect samples for laboratory testing. At the time of this survey, there was a decrease in raveling of the reflection cracks. This problem had been reduced by treating the cracks with SS-1h emulsion and sand. Typical cracking and sealing treatments are shown in Figure 20.

Airport personnel expressed their satisfaction with the performance of the PFC, and pilots stated that the PFC had superior braking characteristics. Additionally, snow and ice removal was accomplished without the aid of chemicals or sand.

Great Falls International Airport was visited in March 1975 to make a survey of the PFC and remove 6-in.-diam samples from the pavement for laboratory testing. At that time, there seemed to be an increasing number of reflected cracks and existing cracks were longer and wider (Figures 21 and 22). Raveling at these cracks was continuing.

STAPLETON INTERNATIONAL AIRPORT

A condition survey of Stapleton International Airport was also conducted in May 1973.[1]

A survey of Stapleton was conducted in October 1974 to test the pavement and remove 6-in.-diam samples from the pavement for laboratory tests. A few additional reflected cracks were observed, and raveling of these cracks was minor. The problem of bond failure between the PFC and existing pavement had not progressed. A joint sealer was being used in

reflected cracks that was performing satisfactory (Figures 23 and 24). No solution for effectively removing the rubber building up on the PFC (Figure 25) had been found.

Airport personnel expressed their satisfaction with the overall performance of the PFC. The maintenance problems caused by reflected cracks, raveling, and bonding of sections of PFC had been greatly reduced.

Stapleton International Airport was visited again in March 1975 to inspect the PFC and obtain 6-in.-diam samples for laboratory testing. There appeared to be more cracks and existing sealed cracks were opening wider. The weather at Denver was cold at the time of inspection, and some ice was observed on the PFC. Ice had formed where water was forced to the surface at sealed cracks (Figure 26). Sealing cracks effectively created a dam in the PFC, and water draining internally in the PFC was forced to the surface. Ice was also observed at longitudinal construction joints. Figure 27 shows a patch of ice on the surface of the PFC melting from the bottom. This condition occurs when air is warmed in the voids of the PFC.

BARTLESVILLE MUNICIPAL AIRPORT

Observations on a field inspection made in May 1973 at Bartlesville Municipal Airport are reported in Reference 1.

A party visited the airport again in November 1974 to conduct additional field tests and remove 6-in.-diam samples from the pavement for laboratory testing. At that time, the PFC was in good condition. Little change could be observed with the exception of some surface wear or stripping of asphalt and minor reflective cracking near the south end of the runway. No raveling at these cracks had occurred. Airport personnel expressed their satisfaction with the performance of the PFC pavement.

Bartlesville was visited again in March 1975 to inspect the PFC and collect samples for laboratory testing. At the time of this inspection, the area of the PFC that had been surface treated with Petroset was darker in color than the untreated area. The reflected cracks at the south end of the runway showed some minor raveling

(Figures 28-30), and there were a few "pop outs" (Figure 31).

SALT LAKE CITY INTERNATIONAL AIRPORT

Observations on the PFC inspection made in May 1973 at this airport were reported in the previous PFC report.[1]

The airfield was visited again in October 1974 to conduct field tests and remove 6-in.-diam samples from the pavement for laboratory testing. At the time of this visit, the pavement was in good condition with some minor reflective cracking and associated raveling of the cracks.

During the summer of 1973, an additional runway was overlayed with PFC; however, this new PFC runway was not available for testing at the time of the 1974 inspection.

A party visited the Salt Lake City Airport in March 1975 to make an inspection of the PFC pavement and to obtain samples for laboratory testing. At the time of this inspection, the PFC was in good condition. There was some minor wear or stripping of asphalt from the surface aggregate. There were also a few pop outs, some raveling, and gouges caused by snow removal equipment.

GREENSBORO--HIGH POINT--WINSTON-SALEM REGIONAL AIRPORT

The first inspection of this PFC was conducted in March 1975. This inspection consisted of a visual observation of condition and performance and removal of 6-in.-diam cores from the pavement for laboratory testing.

The PFC was in excellent condition. A typical view of the surface texture is shown in Figure 32. Minor snow removal equipment damage was noticed in one area (Figure 33). It was reported that some raveling occurred with the passage of a C-141 accompanying a Presidential visit to Greensboro. Some minor stripping or wearing of asphalt from the surface aggregate was observed. The airport manager was pleased with the performance of the PFC, but some pilots voiced the opinion that it caused an increase in tire wear.

LABORATORY EVALUATION OF FIELD SAMPLES

Laboratory evaluation of the field samples was conducted to determine the properties of the in-place PFC. This evaluation allowed a comparison of the laboratory designed mix and the as-constructed mix properties and the effects of time and environment on the binder. Six-in.-diam samples collected in the field inspections provided material for this laboratory testing. To obtain the samples, the pavement was cored through to at least one pavement layer interface below the PFC, and the core was separated at that interface by shearing with a hot knife. The resulting specimen consisted of a PFC layer on a dense core of the underlying pavement. Samples were obtained in and out of traffic areas where possible; however, restricted access on operational runways did not allow this procedure at all sites.

In 1973 and 1974, an acceptable density determination method had not been developed; therefore, the laboratory test results did not include voids and density values until 1975. In 1973 and 1974, the PFC sample was separated from its dense base with a hot knife after the sample was slightly warmed. Prior to testing PFC components, aggregate particles cut during the coring process were removed. The PFC specimen was then broken up and extractions conducted according to ASTM D 2172-72.[4] The gradation was determined according to ASTM C 136-71.[5] The recovered asphalt was tested for penetration and viscosity according to ASTM D 5-73[6] and ASTM D 2170-67,[7] respectively. The binder was recovered according to ASTM D 1856-69.[8]

Laboratory water permeability tests and density determinations in 1975 were conducted according to the procedures described in Reference 1. For these tests, the water permeability was determined prior to separating the PFC from the dense base. The samples were prepared for density determinations by sawing slightly above the PFC-dense base interface. Examination of the sawed faces during density measurements enabled a relative evaluation of densification and uniformity of the aggregate gradation. These sawed faces are shown in Figures 34-43. Where available, samples from in and out of the traffic area are shown.

But where wide variation in gradation was apparent, samples were photographed to show this variation (Figure 39).

The degree of change in the asphalt properties (Tables 3-5) over the evaluation period cannot be considered significant. The amount of hardening or change in consistency (penetration and viscosity) seems to be related more to the original consistency and probably the crude source from which the asphalt was produced than to other factors. The latter is more likely the reason for the significantly low penetration and high viscosity of the asphalt used at the Naval Air Station, Dallas. The lack of correlation of some of the penetration and viscosity values was expected and emphasizes some of the problems associated with choosing correct viscosity grades of asphalt for a particular type and quality of paving.

The bulk density values are of less importance than the associated voids data and permeability data. Figure 44 shows the voids-permeability relationship. It was assumed that some minimum voids requirement could be specified that would insure adequate permeability. However, a preliminary examination of the data in Figure 44 did not clearly indicate this to be the case. The voids and permeability data shown in Table 5 could be used in conjunction with gradation data to identify an optimum voids-gradation-permeability relation. By adopting the percent aggregate passing the No. 8 sieve as a basis for comparison, the minimum requirement of 1000 ml/min permeability as recommended in Reference 1 could be satisfied by the PFC pavements with less than 20 percent passing the No. 8 sieve. Figure 45 shows a plot of laboratory permeability versus percent aggregate passing the No. 8 sieve. This gradation requirement combined with a minimum initial voids total mix requirement of 30 percent would result in a PFC pavement with adequate long-term permeability.

A statistical analysis of the same data can be accomplished by conducting a linear multiple regression analysis. For this analysis, voids total mix and percent passing the No. 8 sieve are taken as independent variables, and permeability is the dependent variable. In effect, it is assumed that an estimate of the dependent variable is given by

$$A_0 + A_1(\% \text{ voids}) + A_2(\% \text{ passing No. } 8)$$

where A_0 , A_1 , and A_2 are constants determined by the least squares method.

An analysis of permeability, voids total mix, and gradation data from Table 5 indicates that an estimate of the permeability P can be made with the following equation:

$$P = 1982 + 40.9(\% \text{ voids}) - 82.0(\% \text{ passing No. } 8)$$

Substituting the minimum percent voids total mix and maximum percent passing the No. 8 sieve recommended above gives

$$P = 1469 \text{ ml/min}$$

The standard error of estimate would be 507 ml/min. Applying this standard error of estimate, the minimum permeability would be above 1000 ml/min at the 82 percent confidence level. Hence, setting the minimum percent voids total mix at 30 percent and the maximum percent passing the No. 8 sieve at 20 percent will insure that for these critical values there is a confidence level of 82 percent with respect to permeability.

FIELD PERFORMANCE

The field performance of the PFC pavements identified in Reference 1 was monitored and observed for significant changes.

The only poor performance of PFC has been at Nashville, where consolidation, rutting, and loss of permeability have occurred. This poor performance cannot be readily explained. There is no direct comparison of all parameters affecting PFC field performance (i.e., binder type, binder grade, aggregate type, gradation, environment, and traffic type and level). The parameters existing in the PFC at Nashville that could contribute to the poor performance are high initial asphalt penetration (101), high binder content (6.75 percent), high percentage of aggregate passing the No. 8 sieve size (29 percent), relatively warm environment, and high traffic level (50,000 air carrier flights per year). It has also been suggested that limestone aggregates are not suitable for PFC mixes. Items that would not contribute to the performance problems are the low residual asphalt penetration (28) after 3 years and the high initial voids total mix (31 percent) as indicated by density determinations out of the traffic area.

No significant problems that could be attributed to the various binders were observed. The rubberized asphalt binders were continuing to perform very well.

Additional cold weather performance was recorded. The number of pop outs caused by freezing water in PFC was not significant. In some instances, comments indicated that ice buildup was slower on PFC than conventional pavement, but once formed, the ice seemed to melt slower. Field observations indicated that the PFC may aid in the removal of patch ice through the convection of warm air under the ice patch. Ice also readily formed where crack sealing of the PFC created dams to the lateral flow of water and retarded the flow and/or forced the water to the surface.

Rubber buildup is continuing to cause concern on some PFC's at this time (Nashville and Stapleton). No attempt has been made to remove the rubber. However, eventually the rubber will have to be removed from some of the pavements.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are believed warranted based on the results of this study:

a. The poor PFC performance at Nashville could have been the combined result of several parameters. There are no definitive data to clarify the performance of limestone aggregate in PFC. However, by following the design method, quality control procedures, and good construction practices recommended as a result of this study, PFC pavements can be constructed with a much higher degree of confidence.

b. Based on evaluations of test results, a change in the aggregate gradation to limit the amount of material passing the No. 8 sieve to 20 percent maximum is recommended. The following table is a suggested gradation reflecting this limitation:

PFC Gradation

Sieve Size	Percent by Weight Passing Sieve
1/2 in.	100
3/8 in.	80-100
No. 4	25-40
No. 8	12-20
No. 200	3-5

c. The asphalt drainage test does not enhance the design procedure and should only be used to gain secondary background information.

d. Based upon the apparent good results obtained at Greensboro, it is recommended that the design procedure in Reference 1 be used, with the exception that the viscosity range be changed to 275 ± 25 centistokes.

e. The minimum permeability desired for PFC is 1000 ml/min. This requirement combined with a minimum initial voids total mix requirement of 30 percent and the new gradation band will result in good, long-term permeability performance.

f. The procedure for conducting the water permeability test and the recommended design procedure are presented in Appendixes A and B, respectively.

Table 1

Facility Locations and Surveys Conducted

Site No.	Location	Date Constructed	Type of Survey	Date Conducted
1	Pease AFB, Portsmouth, N. H.	Sep 72	Visual inspection	Jan 73
			Field testing	Sep 74
			Visual inspection and sampling	Mar 75
2	Hot Springs Airport, Hot Springs, Va.	Sep 72	Observation of construction	Sep 72
			Visual inspection	Nov 72
			Field testing and sampling	Sep 74
			Visual inspection and sampling	Mar 75
3	Nashville Metropolitan Airport, Nashville, Tenn.	Nov 72	Observation of construction	Nov 72
			Visual inspection	Dec 72
			Visual inspection	May 73
			Field testing	Sep 74
			Visual inspection and sampling	Mar 75
4	Naval Air Station, Dallas, Dallas, Tex.	Sep 71	Visual inspection	Mar 72
			Field testing and sampling	Apr 73
			Field testing and sampling	Nov 74
			Visual inspection and sampling	Apr 75
5	Kirtland AFB, Albuquerque, N. Mex.	Sep 71	Visual inspection	Mar 72
			Field testing and sampling	Apr 73
			Field testing and sampling	Oct 74
			Visual inspection and sampling	Apr 75
6	Great Falls International Airport, Great Falls, Mont.	Sep 72	Field testing and sampling	May 73
			Field testing and sampling	Oct 74
			Visual inspection and sampling	Mar 75

(Continued)

Table 1 (Concluded)

Site No.	Location	Date Constructed	Type of Survey	Date Conducted
7	Stapleton International Airport, Denver, Colo.	Sep-Oct 72	Field testing and sampling	May 73
			Field testing and sampling	Oct 74
			Visual inspection and sampling	Mar 75
8	Bartlesville Municipal Airport, Bartlesville, Okla.	Jul 72	Field testing	May 73
			Field testing and sampling	Nov 74
			Visual inspection and sampling	Mar 75
9	Salt Lake City International Airport, Salt Lake City, Utah	Aug-Sep 72	Observation of construction	Aug 72
			Field testing	May 73
			Field testing and sampling	Oct 74
			Visual inspection and sampling	Mar 75
10	Greensboro--High Point--Winston-Salem Regional Airport, Greensboro, N. C.	Sep 74	Design, quality control of construction	Sep 74
			Visual inspection and sampling	Mar 75

Table 2

PFC Construction Data

Site No.	Location	PFC Thickness in.	Basis for Selecting PFC Job-Mix Design: Method	Basis for Selecting PFC Job-Mix Design: Conditions	Asphalt Cement Data: Penetration 1/10 mm	Asphalt Cement Data: Content percent	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Hydrated Lime Content percent	Aggregate Characteristics*: Type	Specific Gravity	Resistance to Abrasion percent	Soundness percent	Mixing Data: Mixing Temperature °F	Viscosity at Mixing, cSt	Remarks
1	Pease AFB	1	Test section		120-150	[illegible]	--	100	92	35	21	--	--	3	1-1/2	Basalt	2.76	13-14	< 1	250	--	No asphalt drainage
2	Hot Springs	3/4	Bitumen drainage test		113	6.75**	--	100	95	36.5	19	--	--	3.1	1-1/2	Granite	--	18.5	1-2	275	270	No asphalt drainage
3	Nashville	3/4	Bitumen drainage test	140°F for [illegible] hr 250°F for 2 hr	101	[illegible].75	--	100	100	41	[illegible]	--	--	3.9	--	Limestone	2.74	24-25	4-5	275	320	No asphalt drainage
4	NAS, Dallas	5/8			47	[illegible]	100	97	52	5.3	--	--	--	--	--	Basalt	--	15-16	--	240	--	
5	Kirtland AFB																					
	Test section 1	3/4			85-100	5.25	100	90	53	25	--	--	--	4	1-1/2	Basalt	--	< 20	--	290†	--	
	Test section 2	3/4			85-100	5.25	100	88	73	43	--	--	--	3	1-1/2	↓	--	< 20	--	260 (max)†	--	
	Test section 3	3/4			60-70	5.3	--	100	93	54	--	--	--	5	1-1/2	↓	--	< 20	--	212†	--	
	Test section 4	3/4			200-300	5.0	--	100	90	46	--	--	--	7	1-1/2	↓	--	< 20	--	212†	--	
	Test section 5	3/4			120-150	5.2	100	85	60	25	--	--	--	3	1-1/2	↓	--	< 20	--	212†	--	
	Test section 6	3/4			120-150	5.25	--	100	93	45	--	--	--	3	1-1/2	↓	--	< 20	--	212†	--	
	Test section 7	3/4			60-70	5.0	100	43	--	--	--	--	--	3	1-1/2	↓	--	< 20	--	290†	--	Asphalt drainage
6	Great Falls	3/4	Test section	Varied asphalt content	60-70	7.0††	--	100	90	35	15	10	--	4	--	Limestone	2.68	22	--	285‡	--	Asphalt drainage‡‡
7	Stapleton	3/4‡‡	Test section	Varied asphalt content and gradation	85-100	7.0	--	100	98	38	20	13	--	3	--	--	--	--	--	325	185	
8	Bartlesville	3/4	Bitumen drainage test	150°F for 15 hr	60-70	7.0	--	--	100	33	20.6	13.6	--	4.1	--	--	--	--	--	275	--	Asphalt drainage§
9	Salt Lake City	3/4‡‡			60-70	5.75	100	97	75	35	15	12	8	4	--	Slag	3.75	12-15	--	325	185	Asphalt drainage
10	Greensboro	3/4‡‡	$2K_c + 4.0$		85-100	6.5	--	100	97	38	15.7	--	4	2	--	Granite	2.82	24	1.7	300	270	No asphalt drainage

* It is assumed that acceptable test methods were used by construction inspectors to determine these data.
** Initial asphalt content was increased from 6.0 to 6.75 percent to alleviate crusting of the mix during hauling.
† This aggregate temperature was specified but was not necessarily obtained.
†† Initial asphalt content was decreased from 7.5 to 7.0 percent when drainage was noticed in the hauling units.
‡ Occurred at asphalt content of 7.5 percent and mixing temperature of 310 F.
‡‡ PFC consisted of rubberized asphalt with 1-1/2 percent neoprene.
§ Occurred at asphalt content of 7.5 percent.

Table 3

1973 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Asphalt: Penetration 1/10 mm	Asphalt: Content* Percent	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min: Field	Laboratory	Average Skid Resistance BPN**: Dry	Wet
4	NAS, Dallas	In	24,508	67.73	9.06	16	5.4	100	100.0	100.0	41.1	16.6	7.5	3.5	1.7	2662		94	56
		Out	--†	--†	--†	--†	--†	100	100.0	100.0	47.2	18.7	8.0	4.0	2.4	4288		92	68
5	Kirtland AFB††																Permeability data not collected.		
	Test section 1	Out	2,507	18.64	3.56	49	4.8	100	81.6	57.0	30.8	25.4	18.7	11.2	7.1	861		96	83
	Test section 2	Out	11,437	41.69	6.21	24	5.4	100	92.1	7[illegible].1	48.5	27.7	19.0	11.6	8.3	1429		87	72
	Test section 3	Out	2,493	18.53	3.38	44	5.3	100	100.0	95.9	55.0	35.1	26.6	17.7	12.0	406		85	67
	Test section 4	Out	2,174	17.96	3.52	47	5.1	100	98.4	83.4	46.2	30.6	21.6	13.3	8.9	121		88	72
	Test section 5	Out	12,293	43.16	6.96	30	5.2	100	90.6	66.9	33.0	21.9	16.7	11.7	8.3	708		94	72
	Test section 6	Out	8,617	37.29	6.07	32	5.5	100	95.9	85.8	51.6	34.8	26.0	16.4	11.0	78		90	71
	Test section 7	Out	4,836	26.99	4.83	34	5.7	100	96.3	87.7	70.4	58.5	43.2	25.2	16.6	0		80	66
	Test section 8	Out	16,052	49.84	7.24	24	4.3	100	53.5	29.6	24.4	21.0	17.4	10.2	5.8	--‡		82	61
6	Great Falls	In	9,744	35.06	5.60	34	6.2	100	98.3	93.7	40.1	20.0	13.8	8.5	4.2	3710		99	80
		Out	--†	--†	--†	--†	--†	100	100.0	97.8	43.2	19.1	11.4	7.0	4.3	3574		100	76
7	Stapleton	In	6,185	40.07	7.00	42	6.3	100	100.0	99.4	46.4	22.1	16.0	9.8	5.8	602			
		Out	5,618	38.28	6.61	45	--†	100	100.0	98.2	40.4	20.7	15.7	9.1	5.1	2334		93‡‡	74‡‡
8	Bartlesville	In	56,443	111.56	13.97	29	5.9	100	100.0	99.3	46.0	25.8	16.4	9.2	6.1	1202		99	75
		Out	47,318	101.38	13.10	28	--†	100	100.0	98.6	44.3	21.6	13.5	7.2	4.4	2122		94	79
9	Salt Lake City	In	10,880	58.52	8.90	31	--†	100	84.6	63.1	25.1	12.1	7.5	3.1	1.5	3101		94	64
		Out	5,072	37.04	8.58	29	4.[illegible]	100	79.9	58.0	23.6	12.6	8.3	3.2	1.5	4039		100	73

Note: Pease AFB, Hot Springs Airport, and Nashville Metropolitan Airport were not included in the 1973 evaluation.
* Based on amount extracted from field core.
** The BPN (British Portable (Tester) Number) represents the frictional property of the PFC as determined using ASTM E 303-69.
† Not enough material was available to conduct this test both in and out of traffic area.
†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.
‡ Permeability was too high to measure.
‡‡ Value is average BPN for the test section at Stapleton; access to the runway itself was restricted.

Table 4

1974 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Penetration 1/10 mm	Content* percent	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min: Field	Laboratory	Average Skid Resistance BPN**: Dry	Wet
1	Pease AFB	In	4,149	28.91	4.98	52	5.0	100	100.0	91.3	38.0	19.6	13.4	7.7	4.8	476	Permeability data not collected.	94	60
		Out	5,535	34.02	5.83	45		100	100.0	95.5	42.6	23.9	16.5	8.5	5.0	2031		94	72
2	Hot Springs	In	8.158	40.40	6.46	33	5.2	100	100.0	98.8	31.7	13.0	9.1	5.8	3.8	3000		94	72
		Out	10,828	56.99	6.90	--+	--+	100	100.0	98.7	40.5	15.5	9.9	5.8	3.8	4800		95	74
3	Nashville	In	6,151	31.25	5.37	38	6.6	100	100.0	99.7	51.5	29.3	17.2	6.3	2.2	108		94	52
		Out	11,139	45.64	6.93	26	--+	100	100.0	100.0	47.8	29.8	20.2	12.6	10.0	1403		88	73
4	NAS, Dallas	In	36,892	79.96	10.18	12	5.7	100	100.0	100.0	38.3	14.1	6.8	3.4	2.4	3216			68
		Out	55,593	98.00	11.88	11	--+	100	100.0	100.0	48.9	20.2	8.3	3.5	2.2	3675		95	66
5	Kirtland AFB††																		
	Test section 1	Out	6,323	27.52	5.00	27	4.6	100	89.7	65.0	35.6	30.1	23.0	13.6	8.2	363		87	63
	Test section 2	Out	13,022	40.85	6.20	22	5.5	100	90.6	79.6	54.0	34.5	26.6	14.9	8.4	1265		83	67
	Test section 3	Out	20,264	48.39	7.21	20	5.3	100	100.0	88.4	49.7	31.0	22.7	14.2	9.0	67		84	63
	Test section 4	Out	4,292	22.53	3.93	32	4.7	100	98.8	92.8	51.2	32.9	25.1	16.8	10.4	33		81	67
	Test section 5	Out	5,850	25.93	4.80	32	3.8	100	86.1	59.3	29.4	20.6	15.8	11.1	7.4	373		82	66
	Test section 6	Out	4,892	23.63	4.31	31	4.3	100	97.6	85.9	48.3	32.3	22.6	14.5	10.1	0		83	62
	Test section 7	Out	--	--	--	--	--	--	--	--	--	--	--	--	--	--		82	68
	Test section 8	Out	13,201	45.20	6.31	23	4.0	100	56.1	25.9	17.7	15.7	12.4	8.9	6.2	--‡		80	63
6	Great Falls	In	10,809	39.24	6.09	27	6.4	100	95.8	85.5	41.5	25.9	20.0	11.8	4.1	1354		95	76
		Out	24,320	61.20	7.99	23	--+	100	100.0	97.0	40.9	18.4	11.2	7.1	4.2	2058		98	83
7	Stapleton	In	11,035	38.58	6.81	38	6.6	100	100.0	99.6	43.9	22.2	16.2	9.2	4.6	67		98	62
		Out	5,500	53.67	8.62	33	--+	100	100.0	97.8	47.8	24.5	18.1	9.8	4.7	718		94	74
8	Bartlesville	In	172,924	218.64	21.92	22	5.6	100	100.0	98.6	44.7	23.7	15.2	8.6	5.8	1529		95	67
		Out	146,148	195.36	23.36	22	--+	100	100.0	99.3	47.1	22.3	13.6	7.1	4.4	1452		96	67
9	Salt Lake City	In	16,667	66.33	10.21	23	5.6	100	89.4	68.1	28.7	14.4	9.4	4.6	2.5	641		--‡‡	61
		Out	16,636	64.24	10.06	23	--+	100	78.1	58.5	24.3	14.9	10.9	6.0	3.4	3027		--‡‡	65
10	Greensboro§	In	--	--	--	--	6.5§§	--	--	--	--	--	--	--	--	--		--	--
		Out	--	--	--	--	--	100	100.0	97.0	38.0	15.7	--	--	2.0	4824		90	63

* Based on amount extracted from field core.
** The BPN (British Portable (Tester) Number) represents the frictional property of the PFC as determined using ASTM E 303-69.
+ Not enough material was available to conduct this test both in and out of traffic area.
†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.
‡ Permeability was too high to measure.
‡‡ Surface was too wet to measure dry BPN.
§ Newly constructed pavement.
§§ Design asphalt content.

Table 5

1975 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Asphalt: Penetration 1/10 mm	Asphalt: Content* percent	Properties of Mix: Percent Voids Total Mix	Properties of Mix: Density pcf	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min: Field	Laboratory
1	Pease AFB	In	3,344	28.45	5.27	46	4.9	27.2	119.2	100**	100**	94.8**	40.2**	22.2**	14.[illegible]**	7.6**	4.5**		542
		Out	4,243	26.80	5.05	49	5.2	28.2	114.2										1591
2	Hot Springs	In	12,852	48.31	7.48	30	5.2	32.3	109.3	--	--	--	--	--	--	--	--		2490
		Out	20,765	66.85	9.48	25	5.0	39.3	96.7	--	--	--	--	--	--	--	--		3859
3	Nashville	In	7,775	35.97	6.02	31	6.3	17.1	128.0	--	--	--	--	--	--	--	--		--
		Out	18,213	59.75	8.04	24	5.4	31.0	108.0	--	--	--	--	--	--	--	--		1286†
4	NAS, Dallas	In	59,706	99.00	12.36	8	5.3	41.0	104.1	100	100	100	37.1	13.3	6.1	3.0	2.1		2412
		Out	71,979	110.02	13.02	9	5.0	42.9	101.2	100	100	100	47.7	19.6	7.9	3.5	1.9		3508
5	Kirtland AFB††																		
	Test section 1	Out*	8,330	32.08	5.37	31	5.0	24.3	121.5	100	91.3	68.9	40.6	3[illegible].0	26.9	15.0	8.4		1591
	Test section 2	Out*	8,237	37.50	6.09	21	4.6	26.0	119.2	100	90.6	75.8	46.8	25.8	18.1	11.8	8.2		853
	Test section 3	Out*	19,549	49.39	7.42	20	5.0	21.8	126.6	100	98.0	89.7	48.8	30.5	21.4	12.9	7.9		300
	Test section 4	Out*	5,742	21.06	3.90	36	4.6	27.5	118.3	100	98.6	90.2	51.9	33.5	25.1	16.6	10.1	No flow	19
	Test section 5	Out*	6,693	25.55	4.95	28	4.7	30.3	112.7	100	89.6	73.8	41.2	29.2	22.5	13.9	8.1		780
	Test section 6	Out*	5,616	24.77	4.58	28	5.0	24.6	123.6	100	99.3	88.9	50.9	34.2	23.8	14.6	10.0		111
6	Great Falls	In	2,944	30.22	5.13	34	6.7	17.7	123.4	100	100	95.1	39.4	18.9	12.6	8.0	4.2		776
		Out	16,872	48.81	7.03	25	5.8	28.6	108.6	100	100	95.9	45.2	20.5	12.5	7.5	4.4		3508
7	Stapleton	In	7,781	46.27	7.97	33	6.3	16.0	127.3	100	98.7	96.7	46.4	26.1	19.7	10.3	4.9		917
		Out	11,730	56.04	9.19	30	6.0	20.8	120.4	100	99.0	95.6	53.1	29.3	22.0	11.5	5.5		977
8	Bartlesville	In	217,062	235.37	24.44	21	5.6	24.3	113.6	100	100	99.2	44.8	24.1	14.9	8.4	5.6		1029
		Out	183,404	211.79	22.58	20	5.6	27.2	109.2	100	100	97.4	45.0	22.2	13.6	7.2	4.5		1575
9	Salt Lake City	In	34,674	121.14	16.12	15	4.6	24.1	145.4	100	87.7	69.7	32.9	16.5	10.5	5.5	3.1		1429
		Out	29,641	84.52	13.23	19	4.7	30.3	133.3	100	92.3	72.1	32.0	16.8	11.7	5.9	3.0		1354
10	Greensboro	In	5,549	39.08	7.30	49	6.0	28.9	112.9	100**	100**	98.1**	49.5**	19.0**	10.5**	4.8**	2.7**		2573
		Out	5,179	39.41	7.26	44	6.2	28.4	113.7										3508

* Based on amount extracted from field core.

** Due to limited amount of material available, combined gradation was run.

† Permeability decreased markedly on samples taken progressively toward runway center line.

†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.

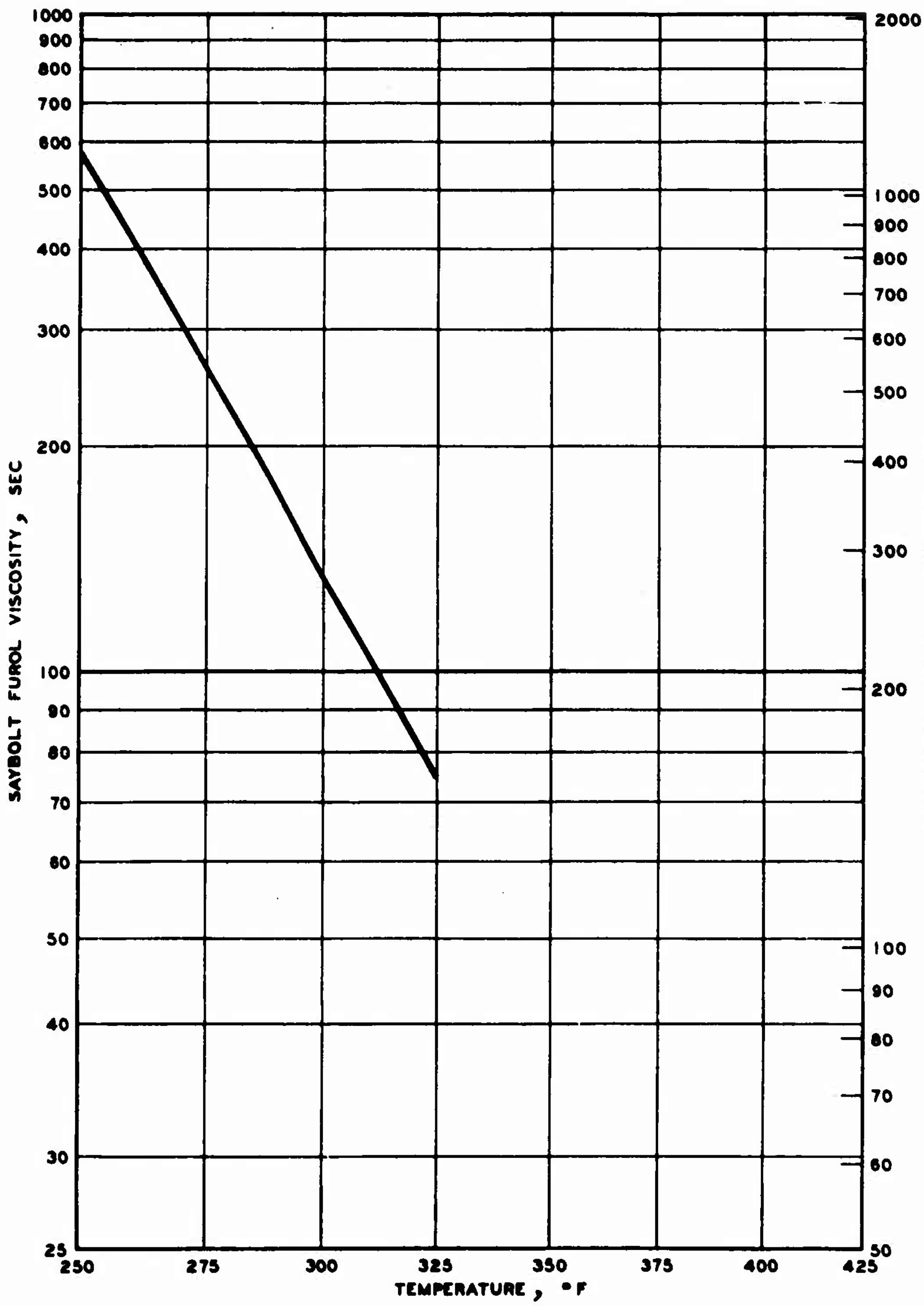


Figure 1. Temperature-viscosity relation for neoprene-modified asphalt (Greensboro)

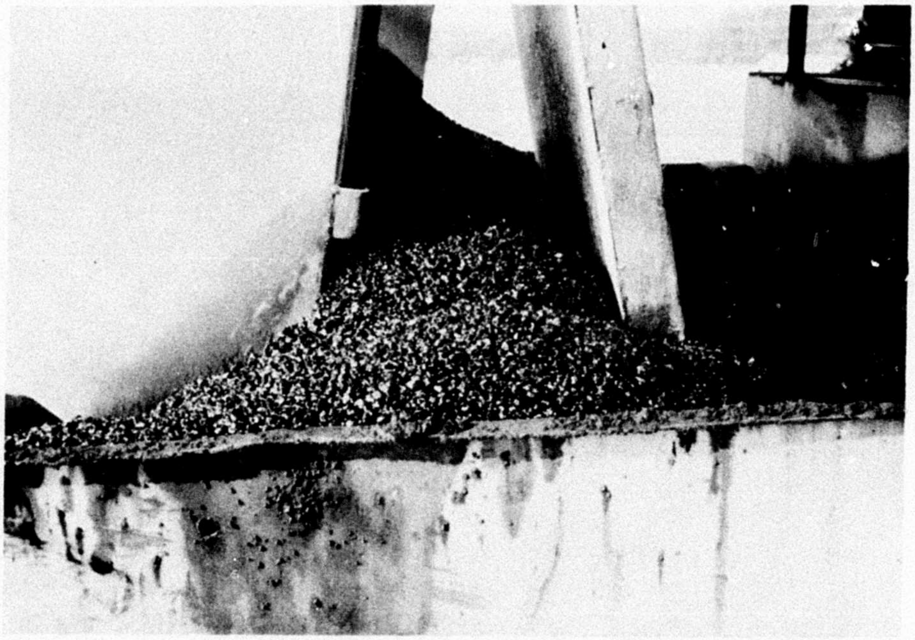


Figure 2. PFC mixture being placed in laydown machine hopper (Greensboro)

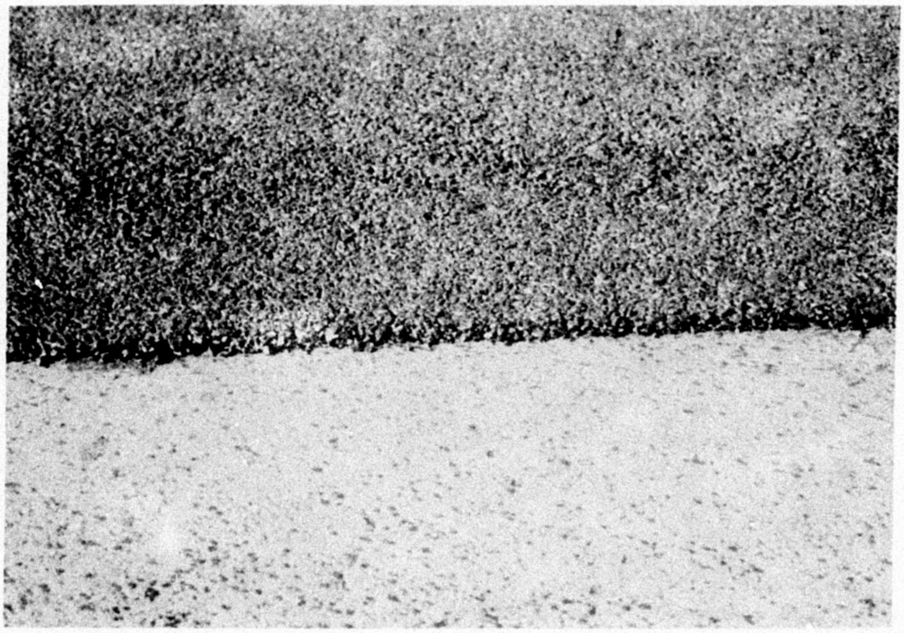


Figure 3. Closeup view of edge of compacted PFC and surface texture (Greensboro)

Figure 4. Finished PFC (Greensboro)

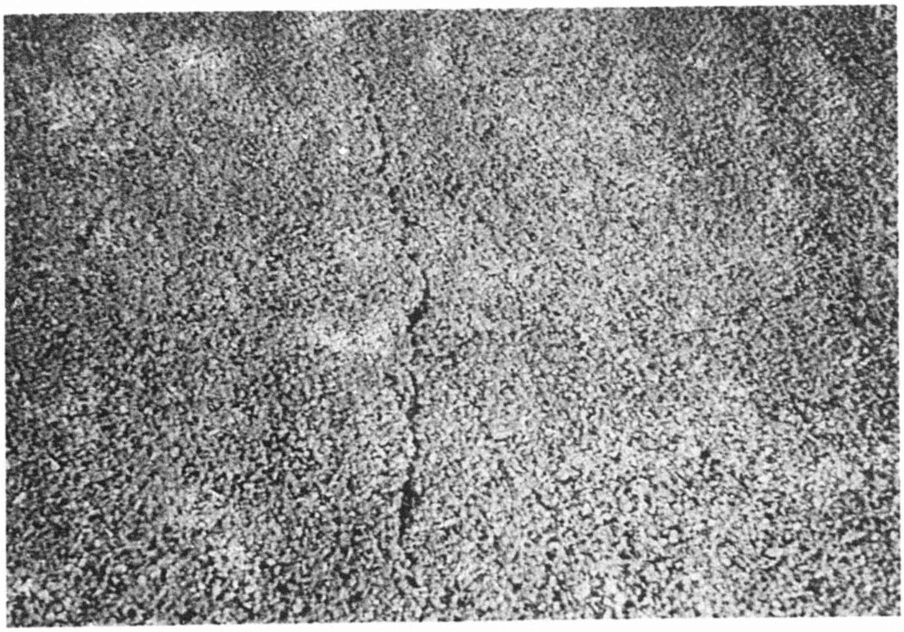


Figure 5. Reflected crack (Pease)

Figure 6. Longitudinal reflected cracks sealed with Petroset (Pease)

Figure 7. Jet blast damage (Pease)

Figure 8. Rubber buildup (Pease)

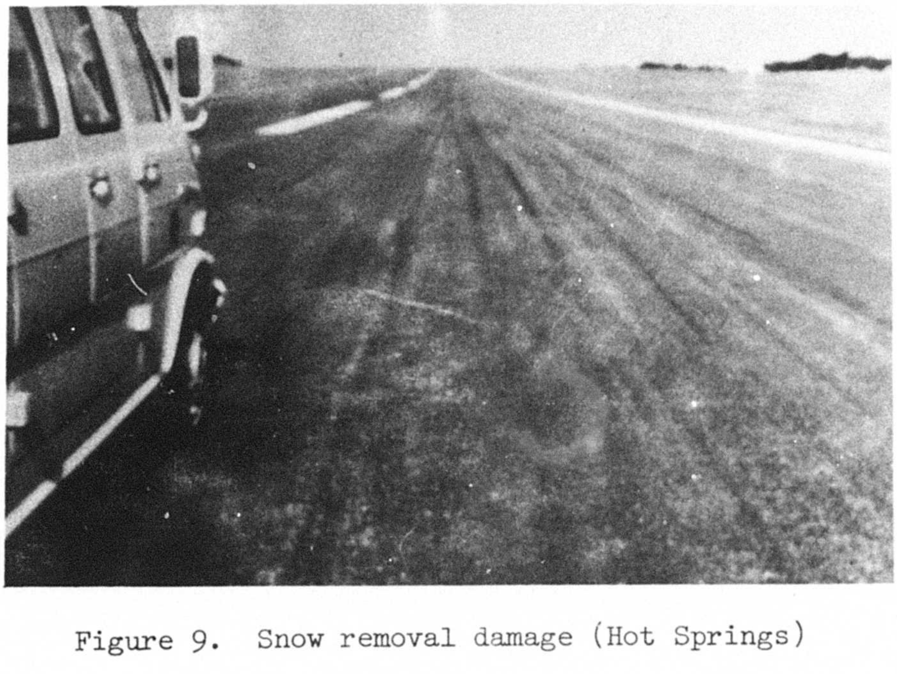


Figure 9. Snow removal damage (Hot Springs)

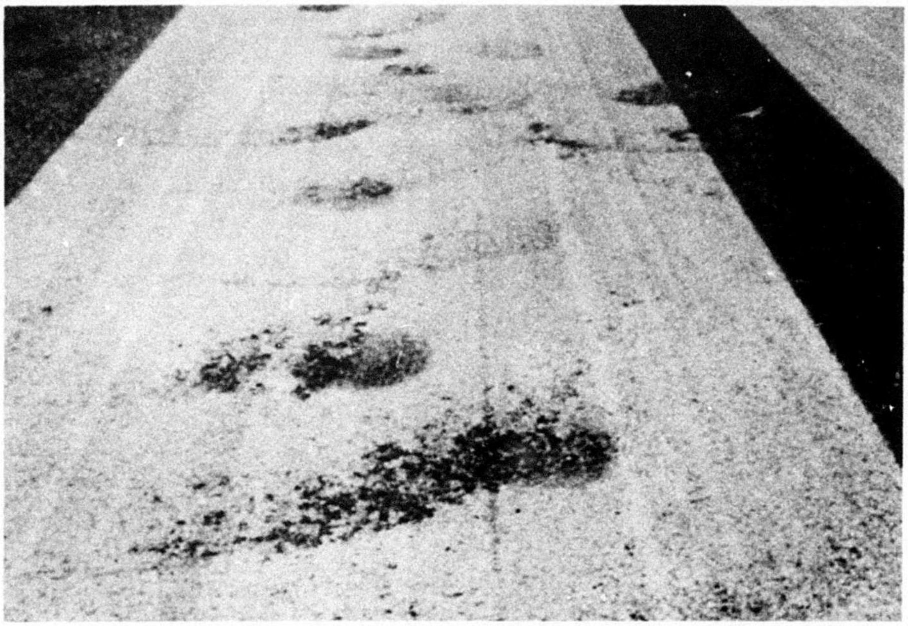


Figure 10. Damage from locked-wheel turns (Hot Springs)

Figure 11. Water from coring operation running in rutted wheel path (Nashville)

Figure 12. Tire print in flushed asphalt (Nashville)

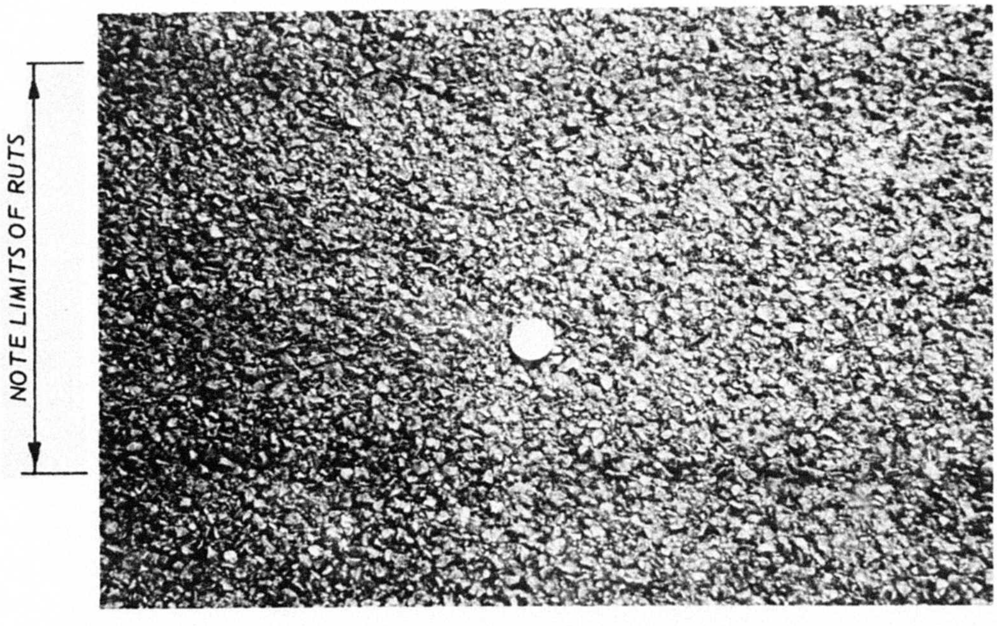


Figure 13. Wheel path rut (Nashville)

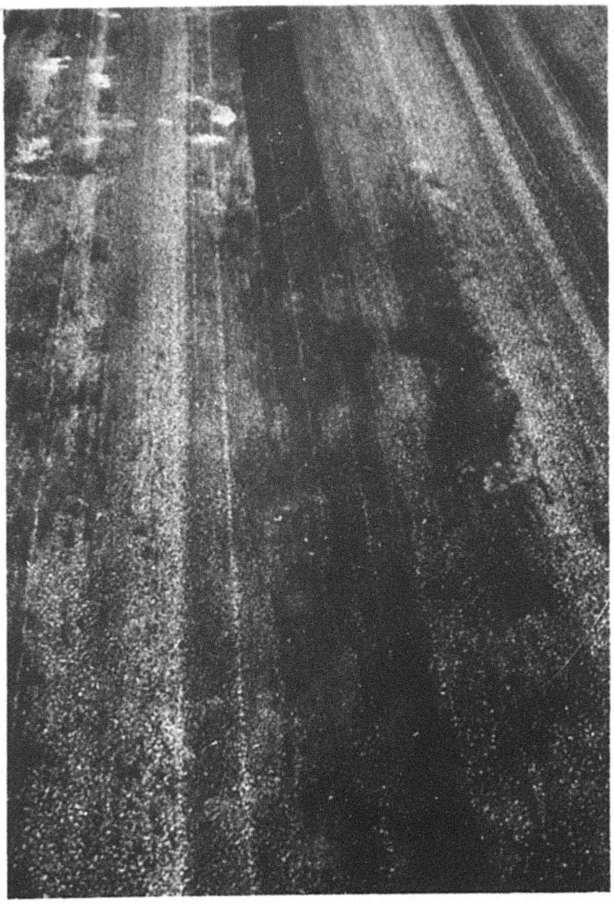


Figure 14. Surface texture and rubber buildup (Nashville)

Figure 15. General view of PFC condition (Nashville)

Figure 16. Observed PFC water drainage and jet blast damage (Dallas)

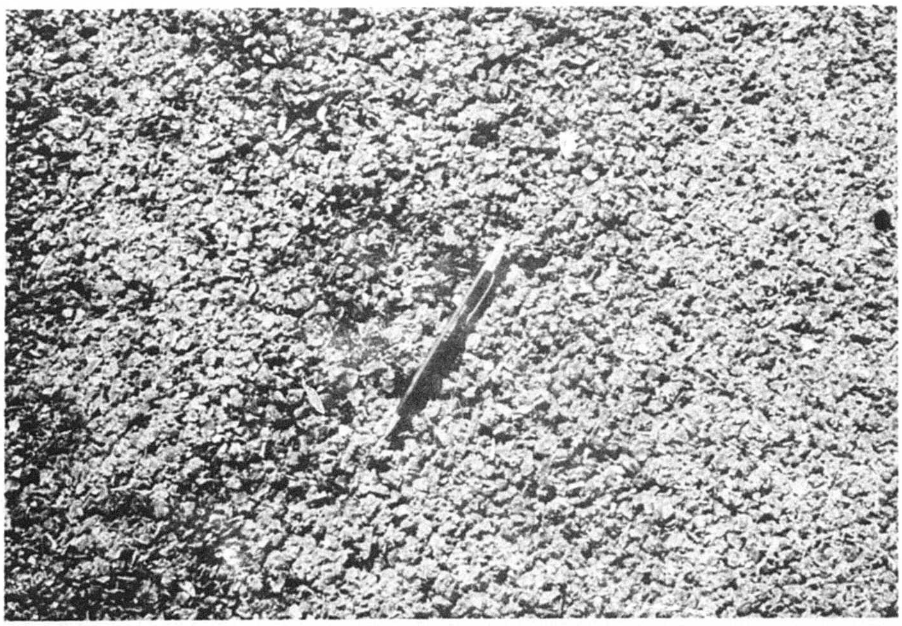


Figure 17. PFC surface texture (Dallas)

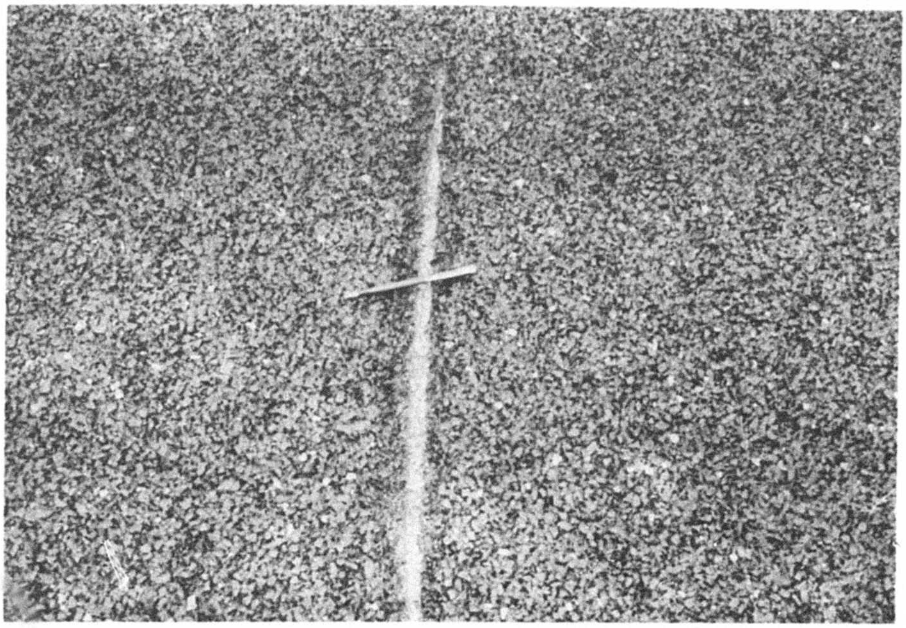


Figure 18. Arrester hook damage (Dallas)

Figure 19. Reflected crack (Dallas)

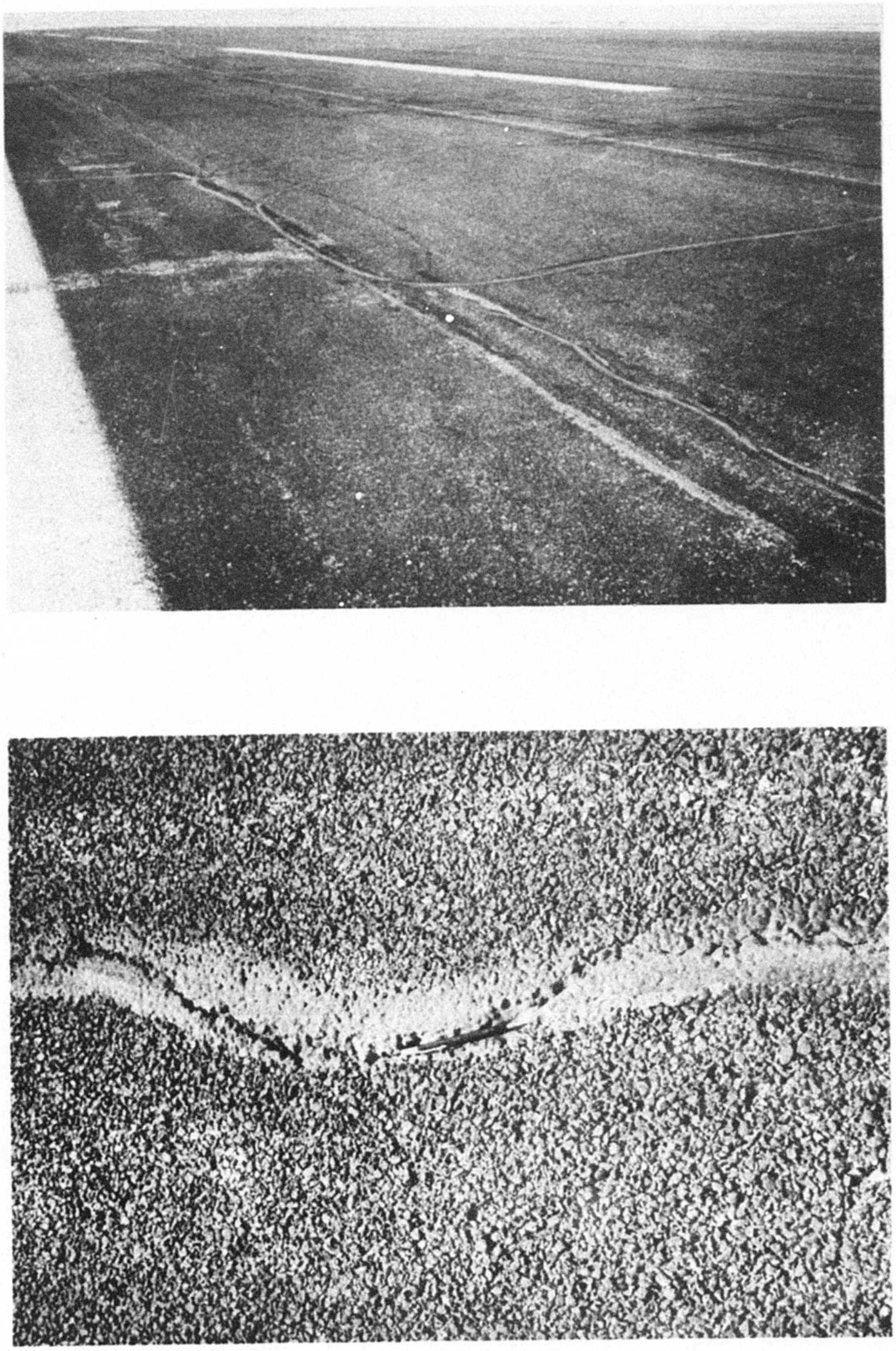
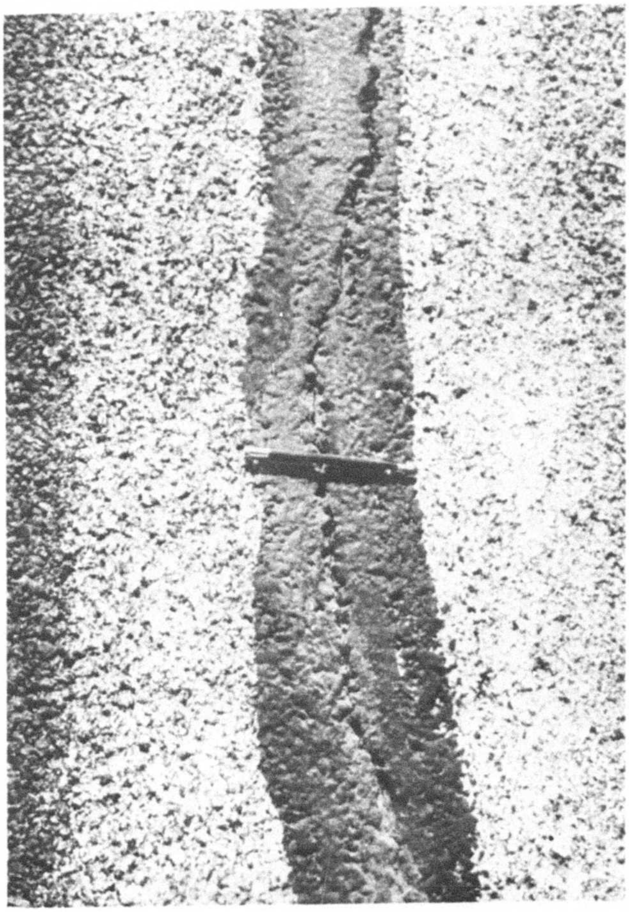


Figure 20. Sealed reflected cracks (Great Falls) (sheet 1 of 2)



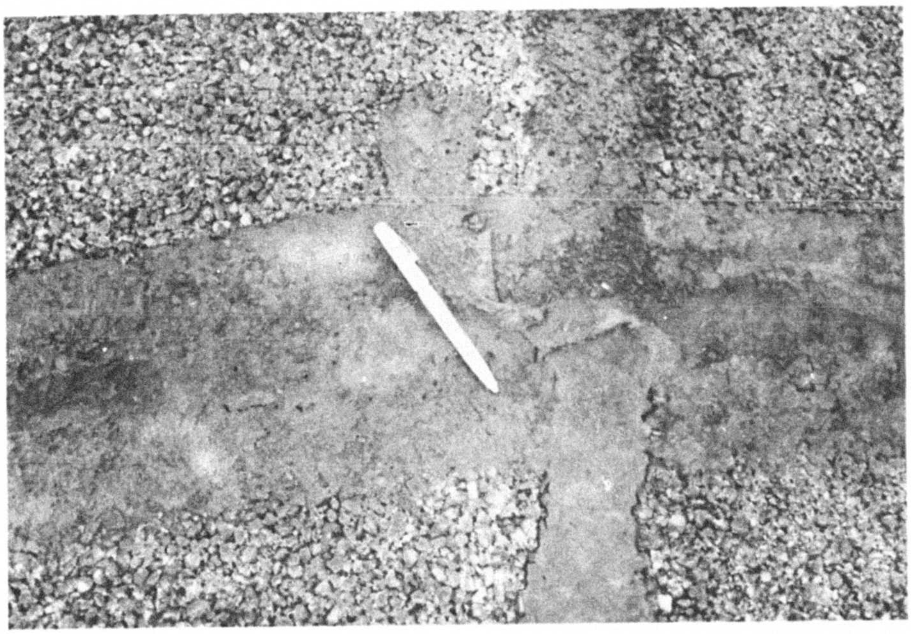


Figure 20. (sheet 2 of 2)

Figure 21. Reflected crack (Great Falls)

Figure 22. Widened reflected crack (Great Falls)

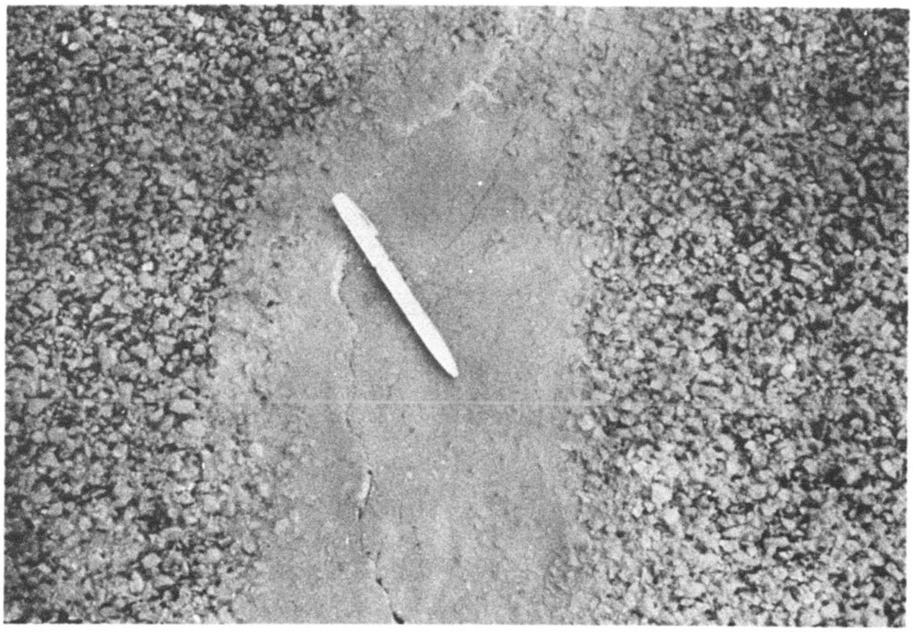


Figure 23. Sealed reflected crack (Stapleton)

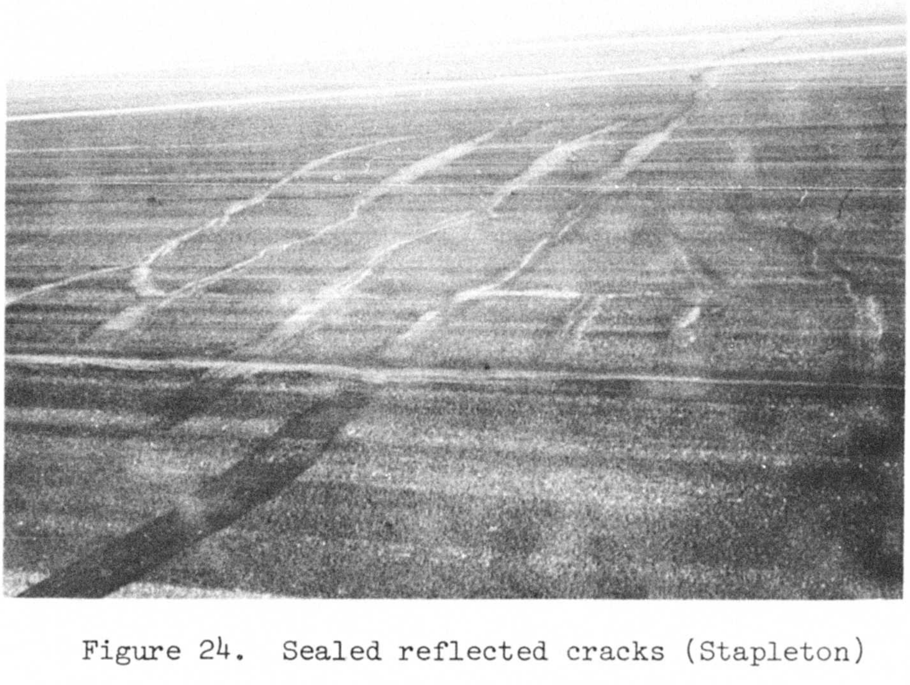


Figure 24. Sealed reflected cracks (Stapleton)

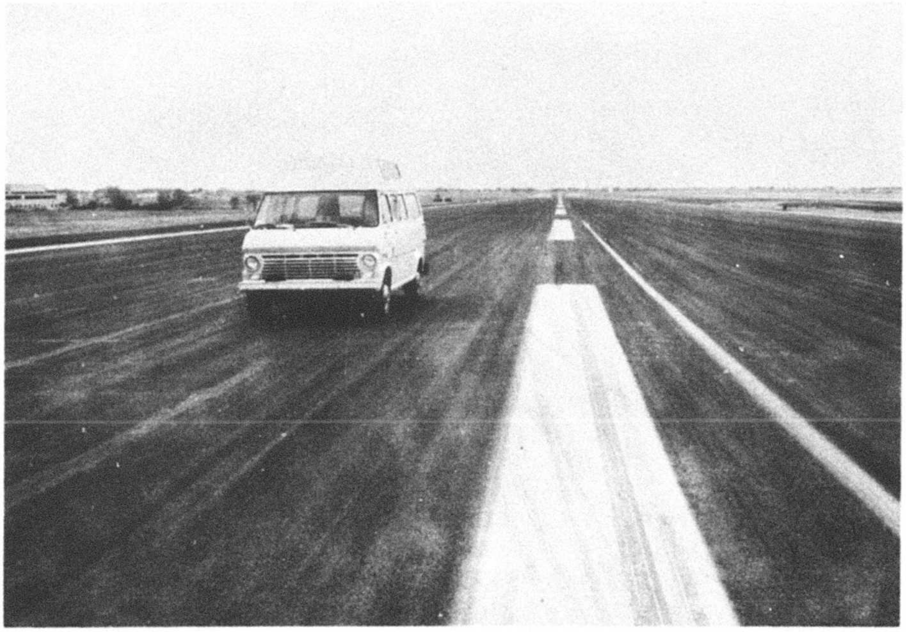


Figure 25. Rubber buildup (Stapleton)

Figure 26. Ice along sealed crack (Stapleton)

Figure 27. Ice patch melting from bottom (Stapleton)

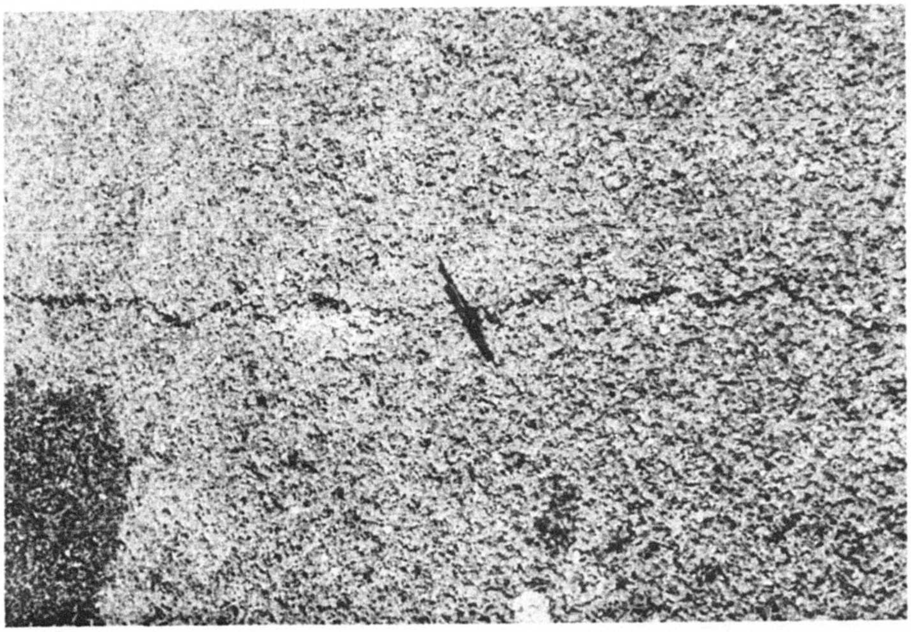


Figure 28. Closeup of reflected crack (Bartlesville)

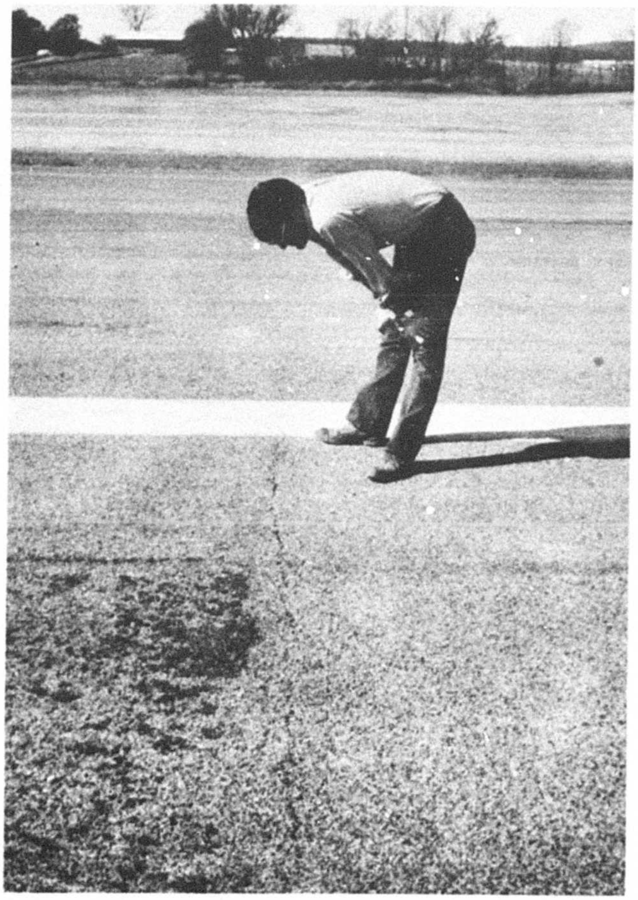


Figure 29. Reflected crack
(Bartlesville)

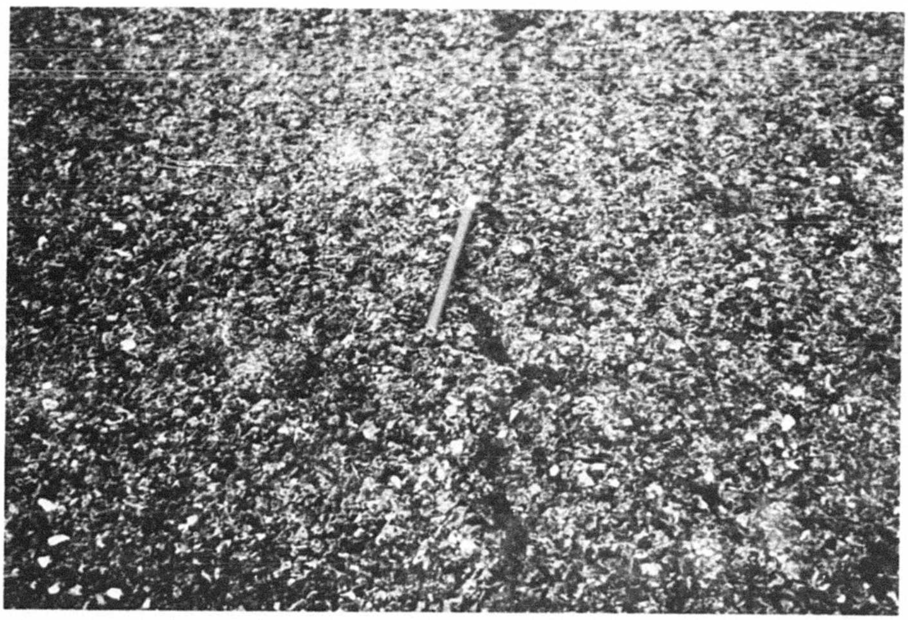


Figure 30. Raveling at reflected crack (Bartlesville)

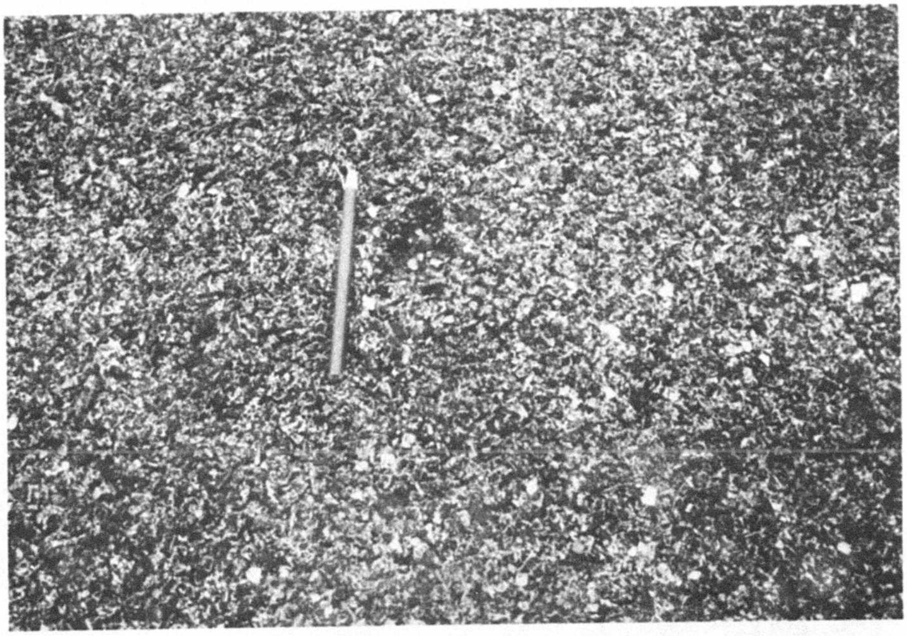


Figure 31. Pop out (Bartlesville)

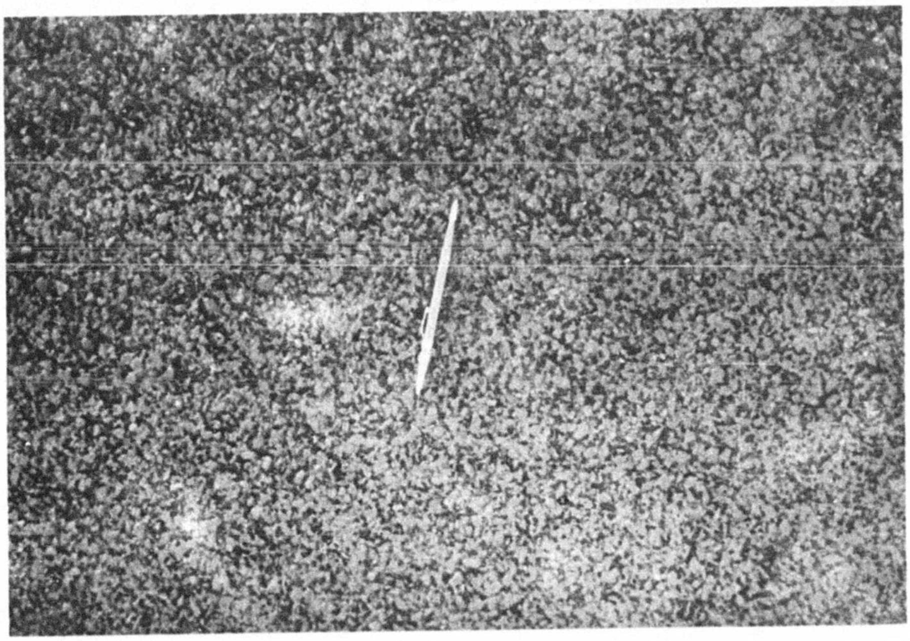


Figure 32. PFC surface texture (Greensboro)

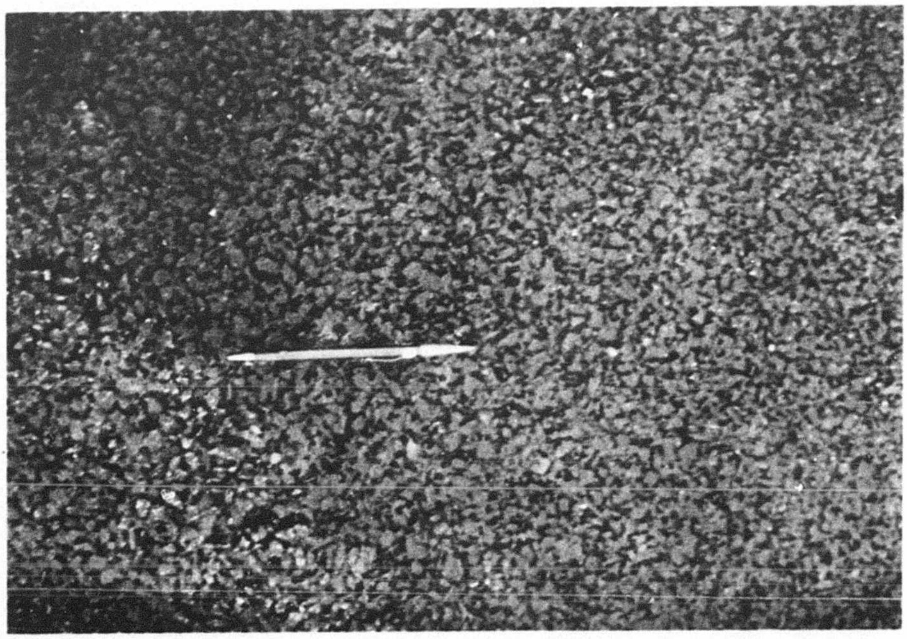
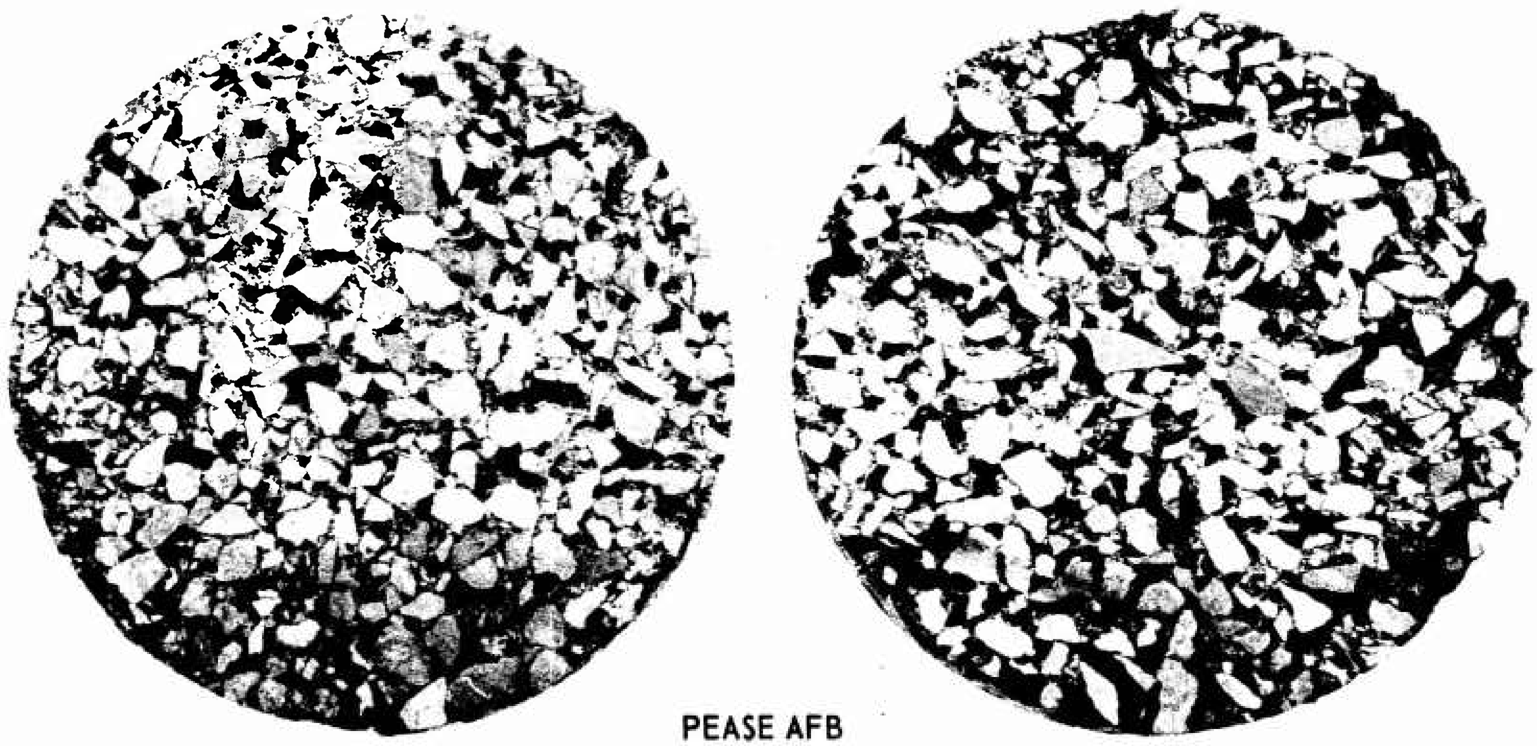


Figure 33. Minor snow removal equipment damage (Greensboro)



PEASE AFB

IN OUT

Figure 34. Sawed faces of Pease PFC samples

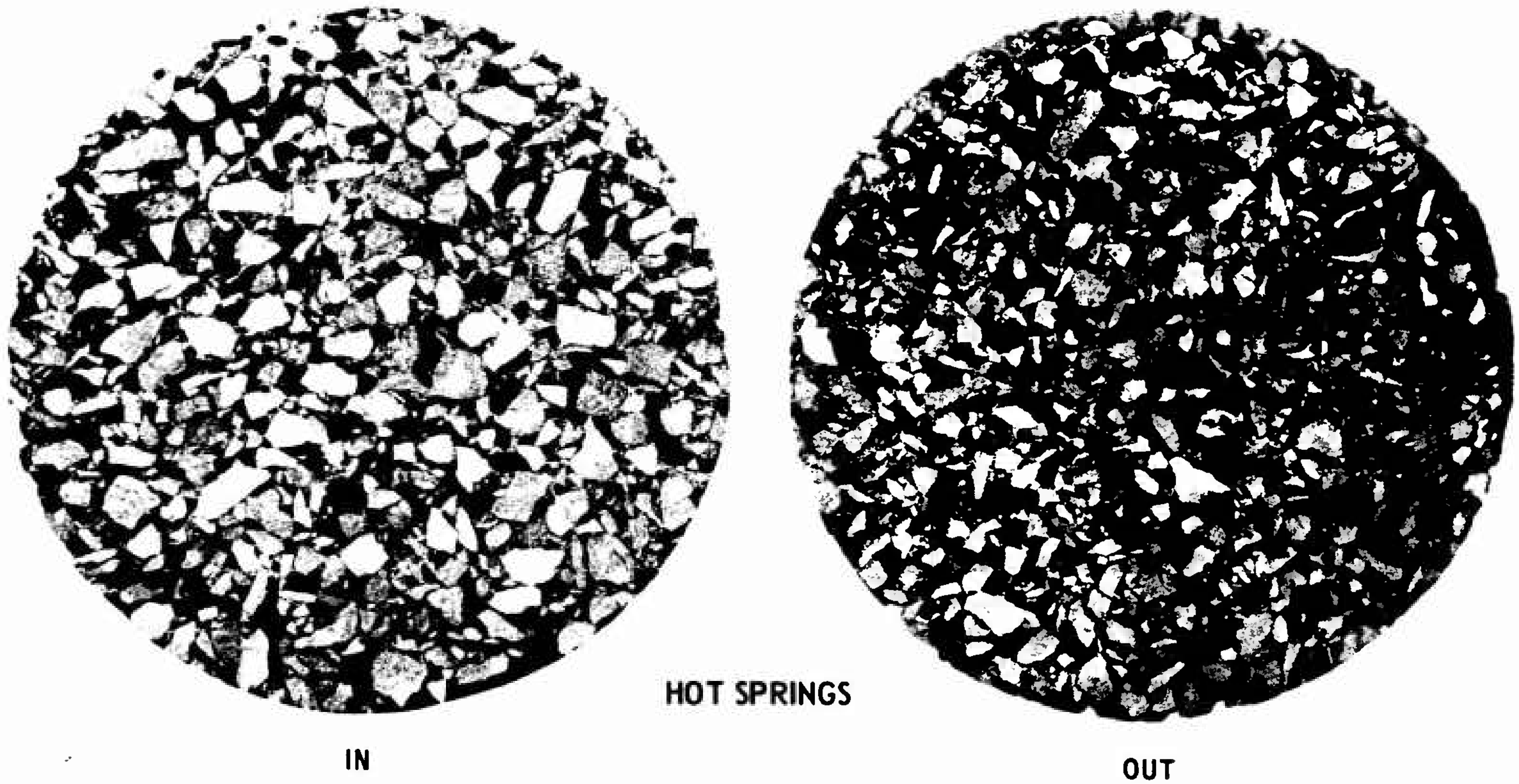


Figure 35. Sawed faces of Hot Springs PFC samples

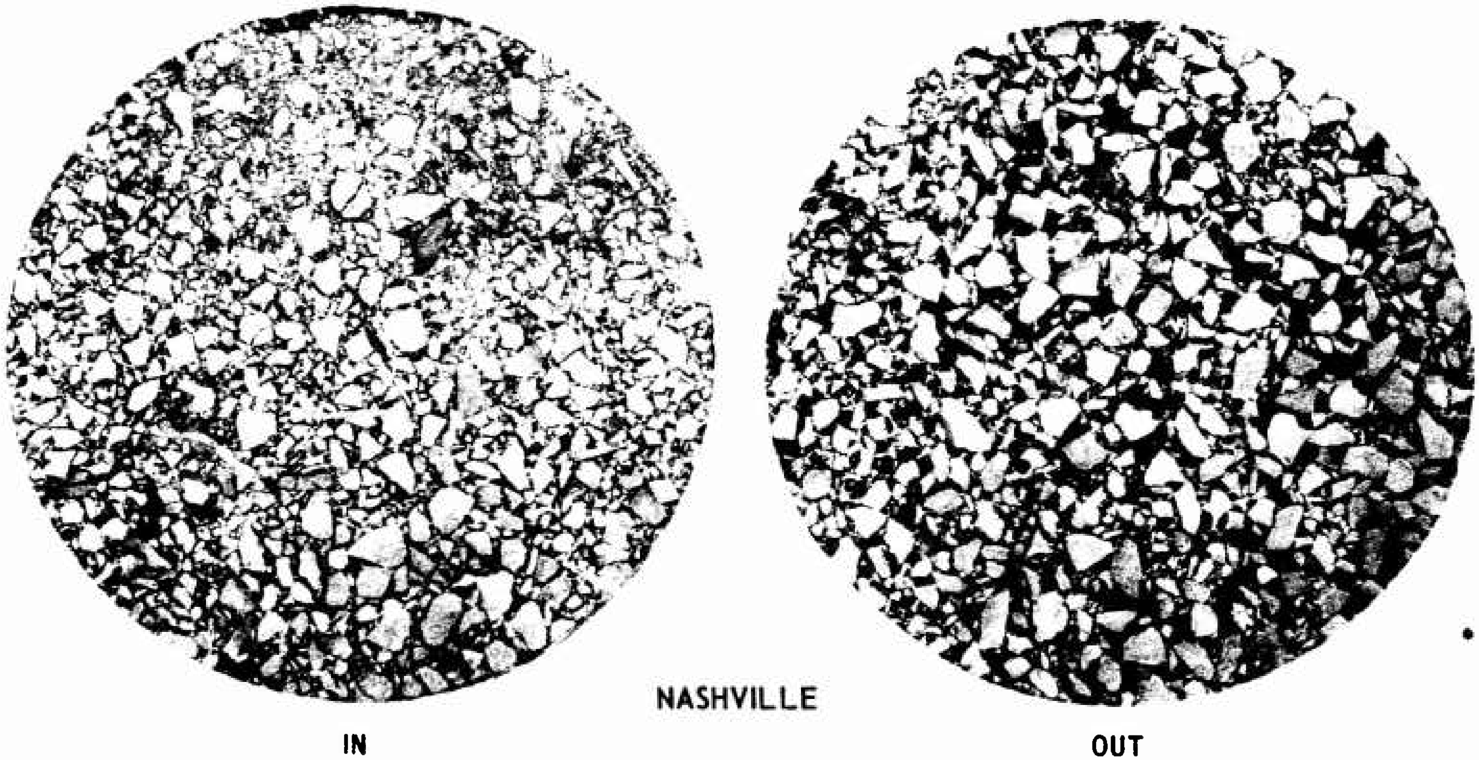


Figure 36. Sawed faces of Nashville PFC samples

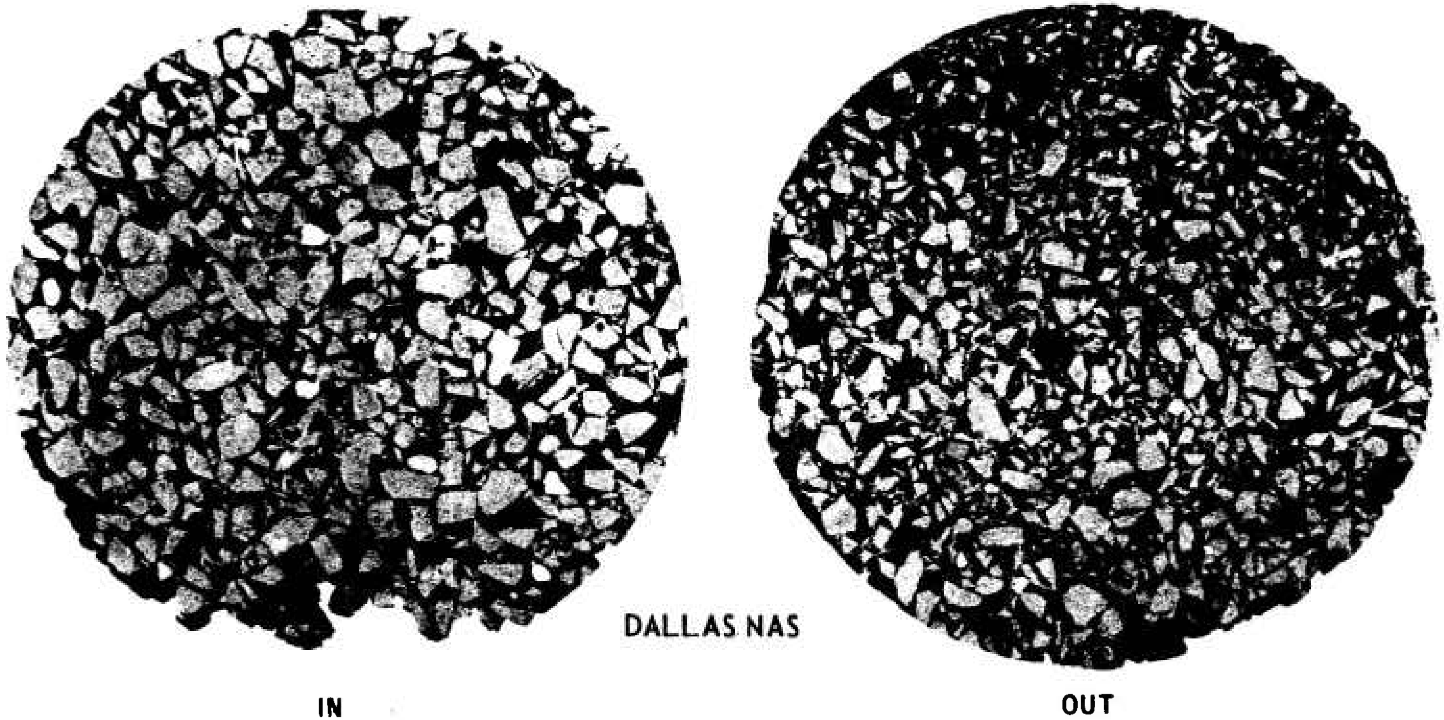


Figure 37. Sawed faces of Dallas PFC samples

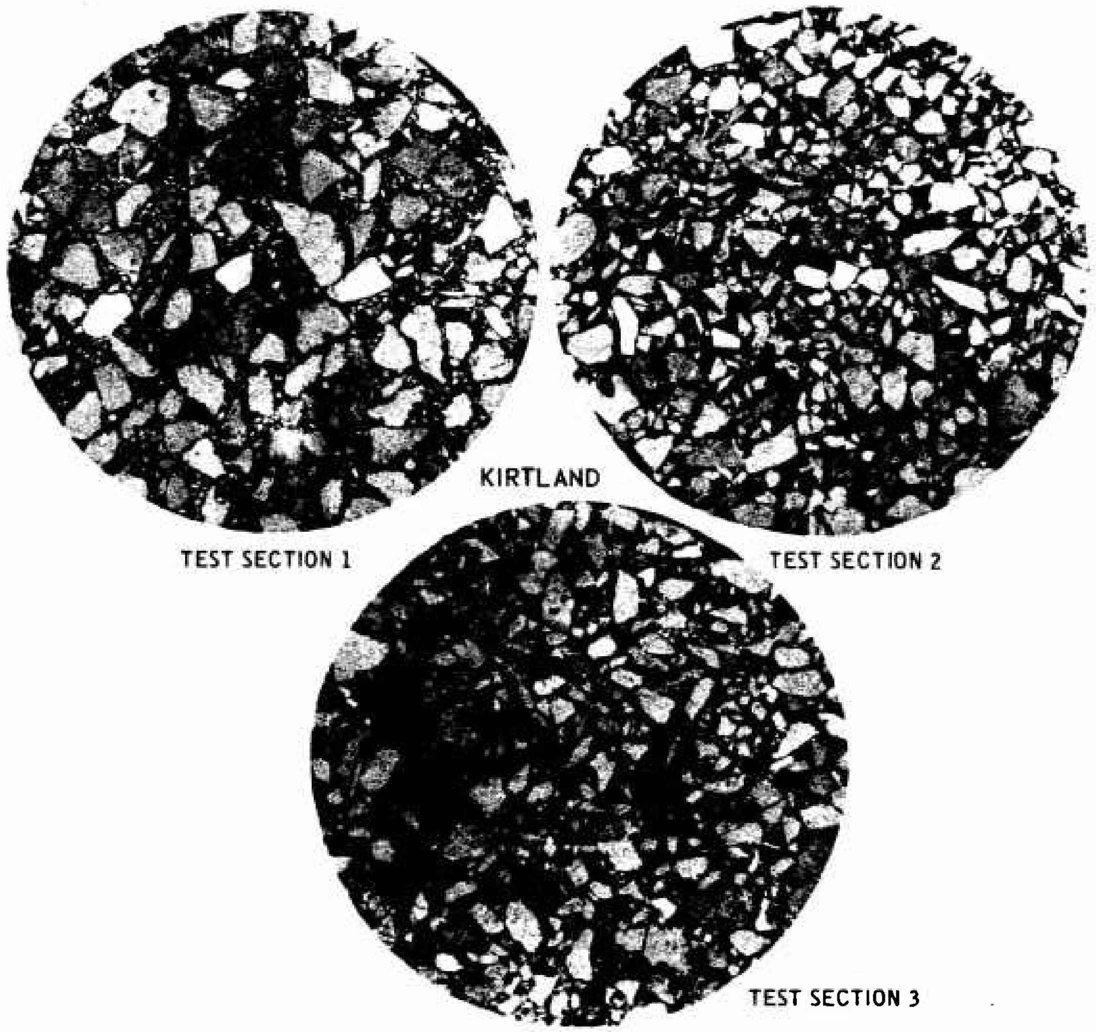


Figure 38. Sawed faces of KAFB PFC samples (sheet 1 of 2)

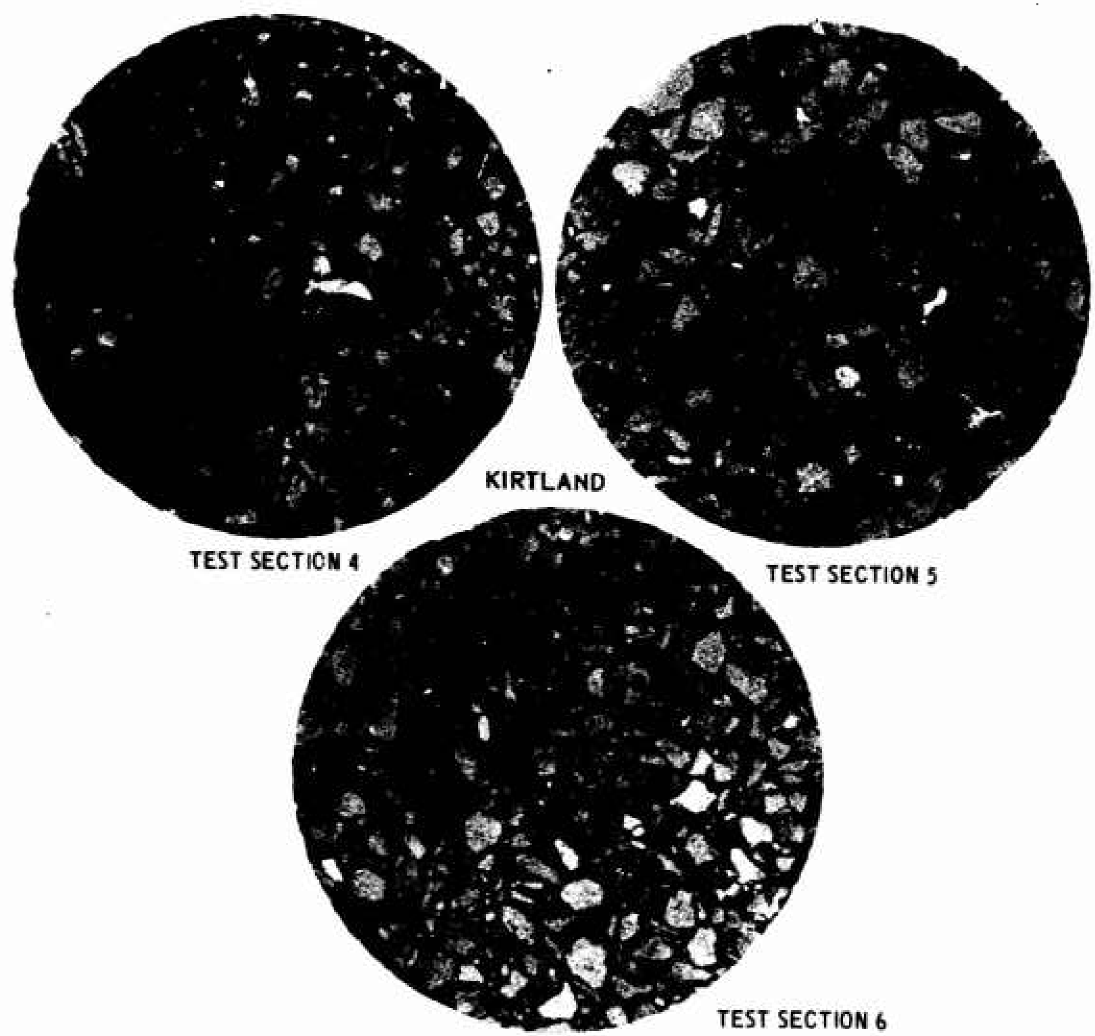


Figure 38. (sheet 2 of 2)

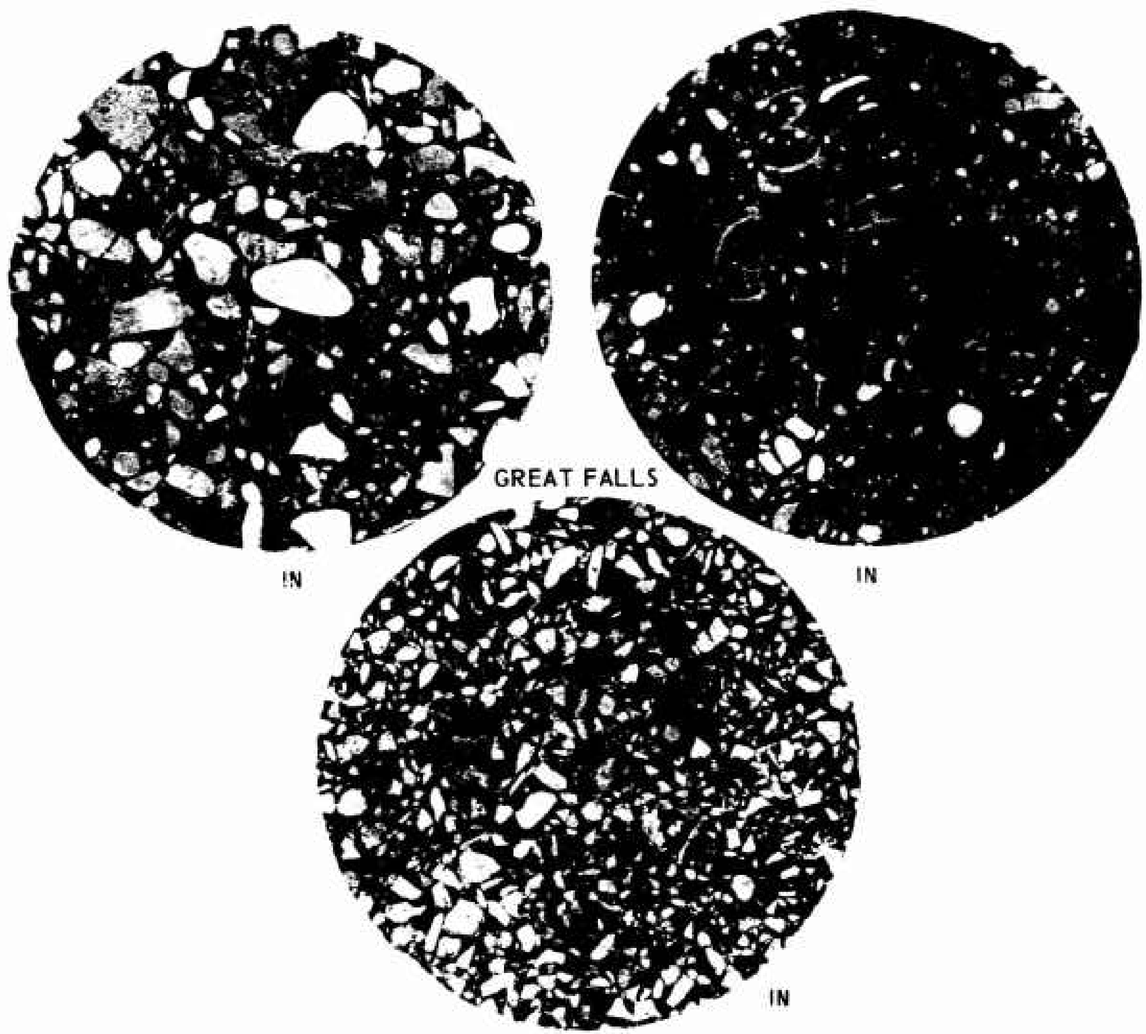


Figure 39. Sawed faces of Great Falls PFC samples

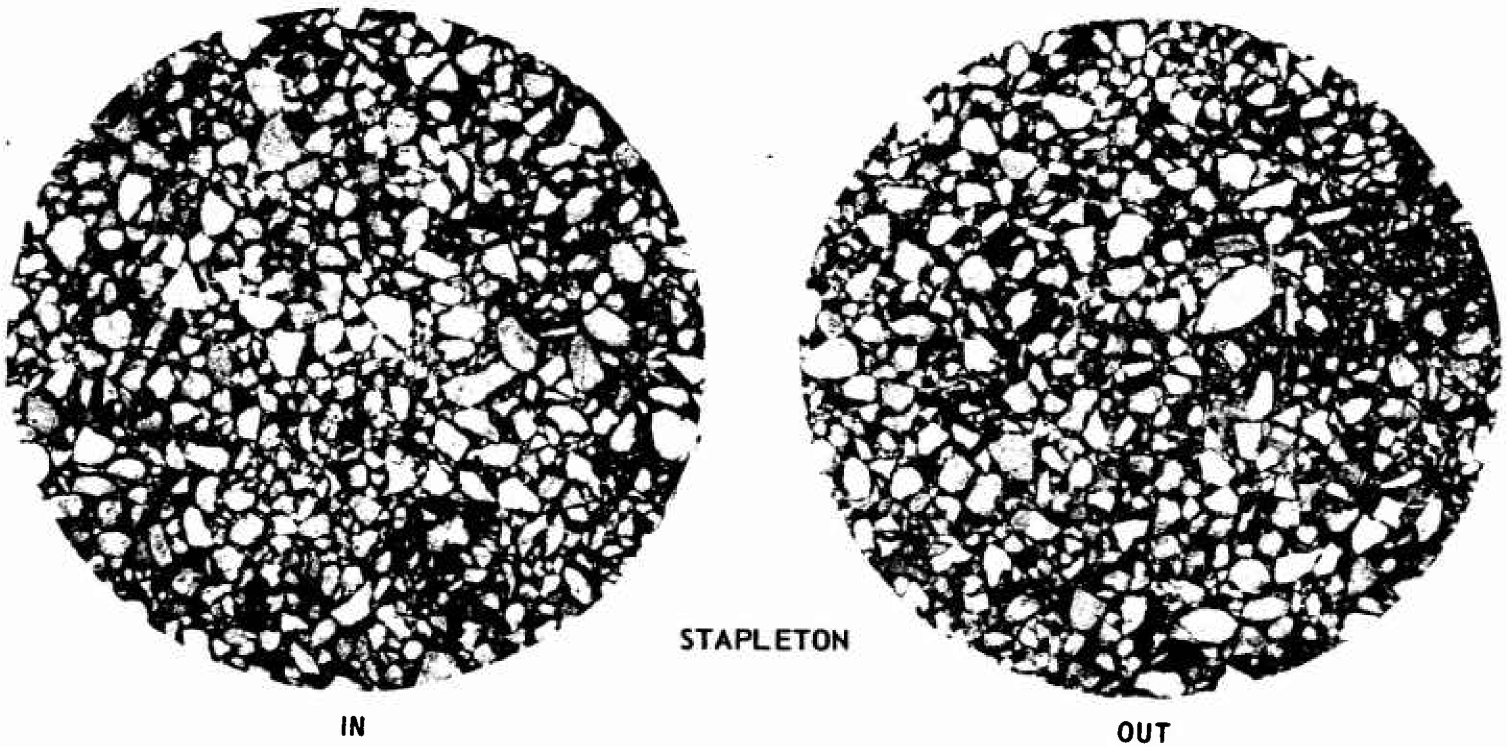


Figure 40. Sawed faces of Stapleton PFC samples

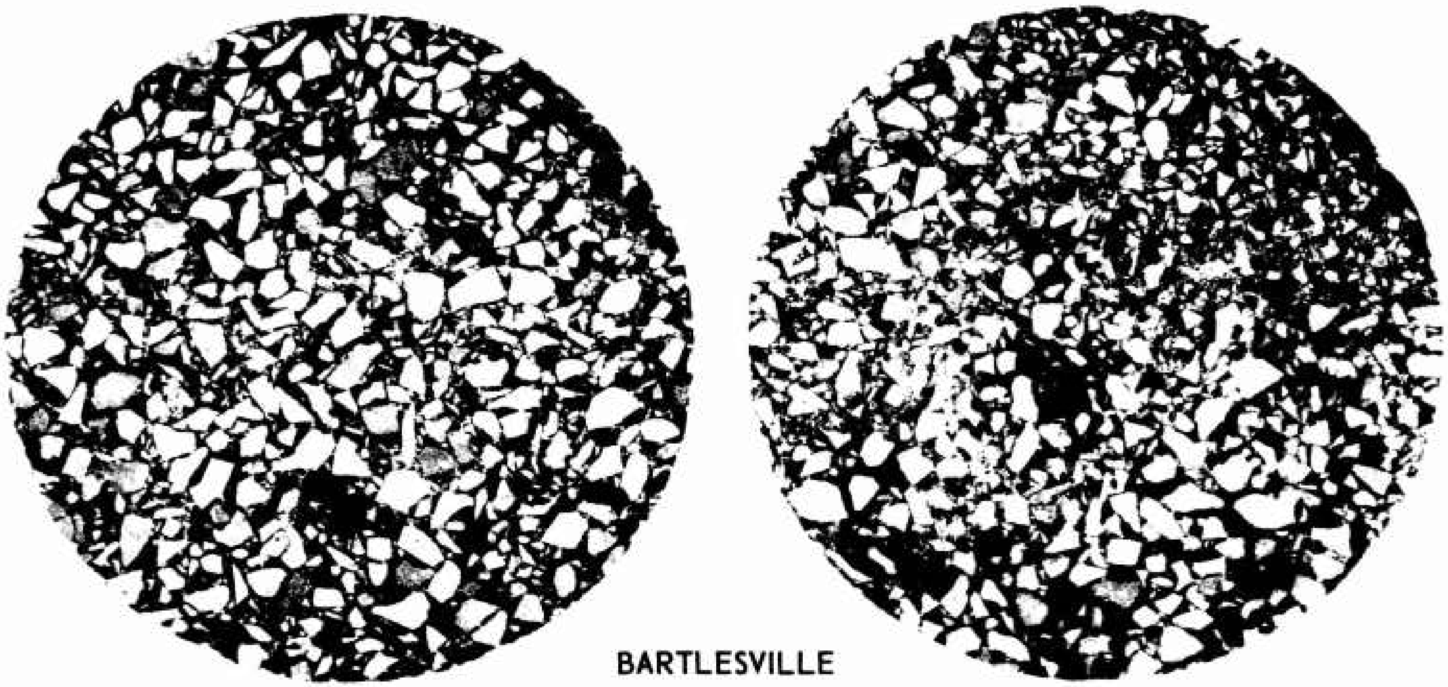


Figure 41. Sawed faces of Bartlesville PFC samples

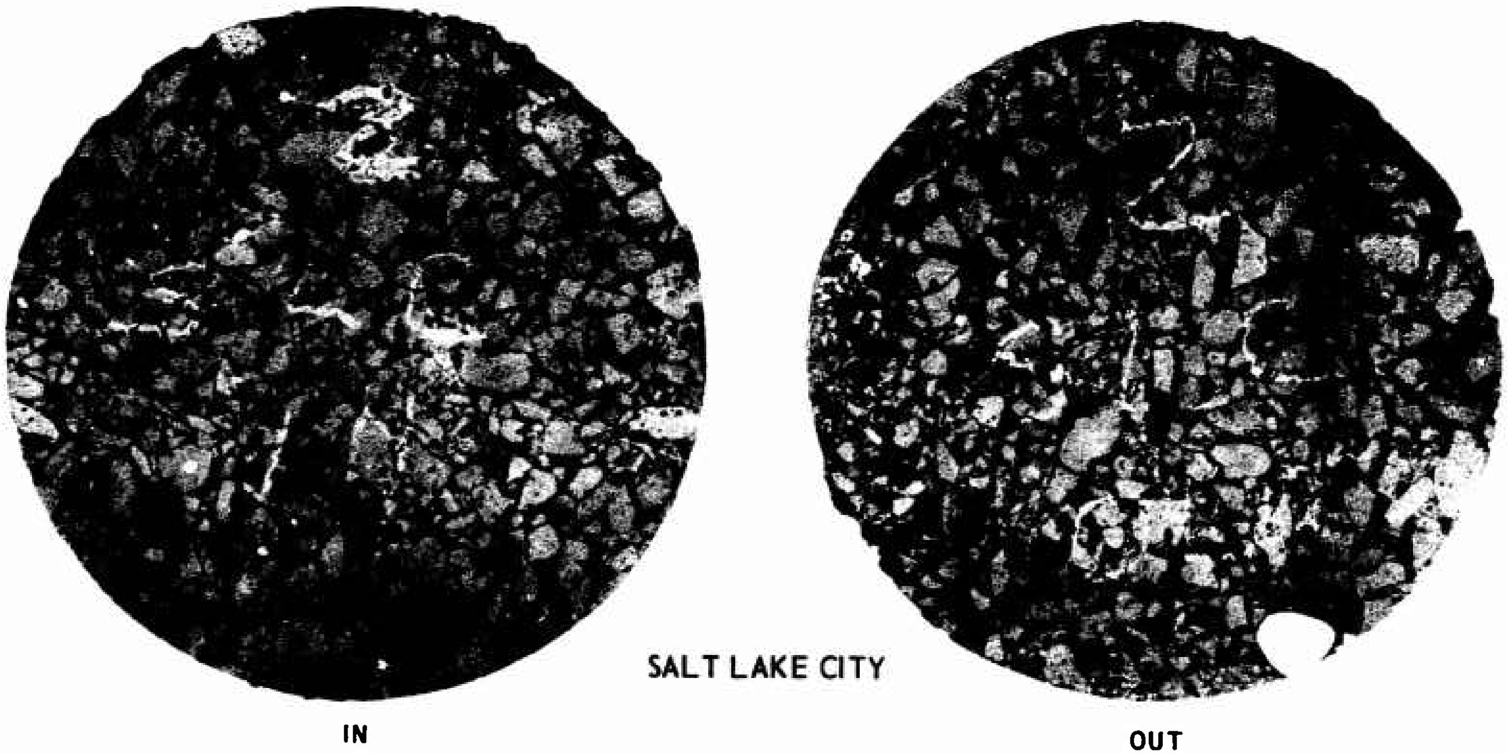


Figure 42. Sawed faces of Salt Lake City PFC samples

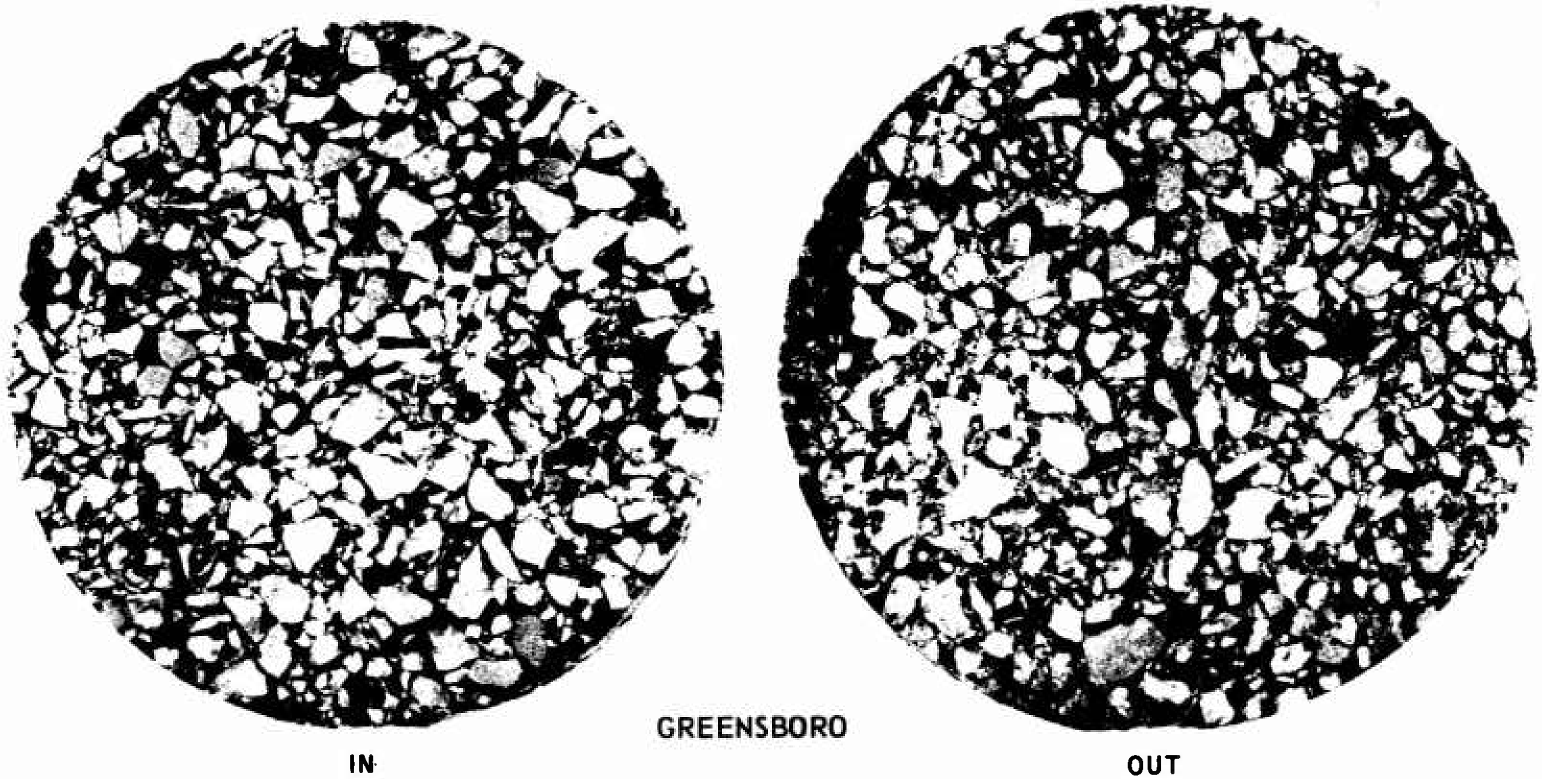


Figure 43. Sawed faces of Greensboro PFC samples

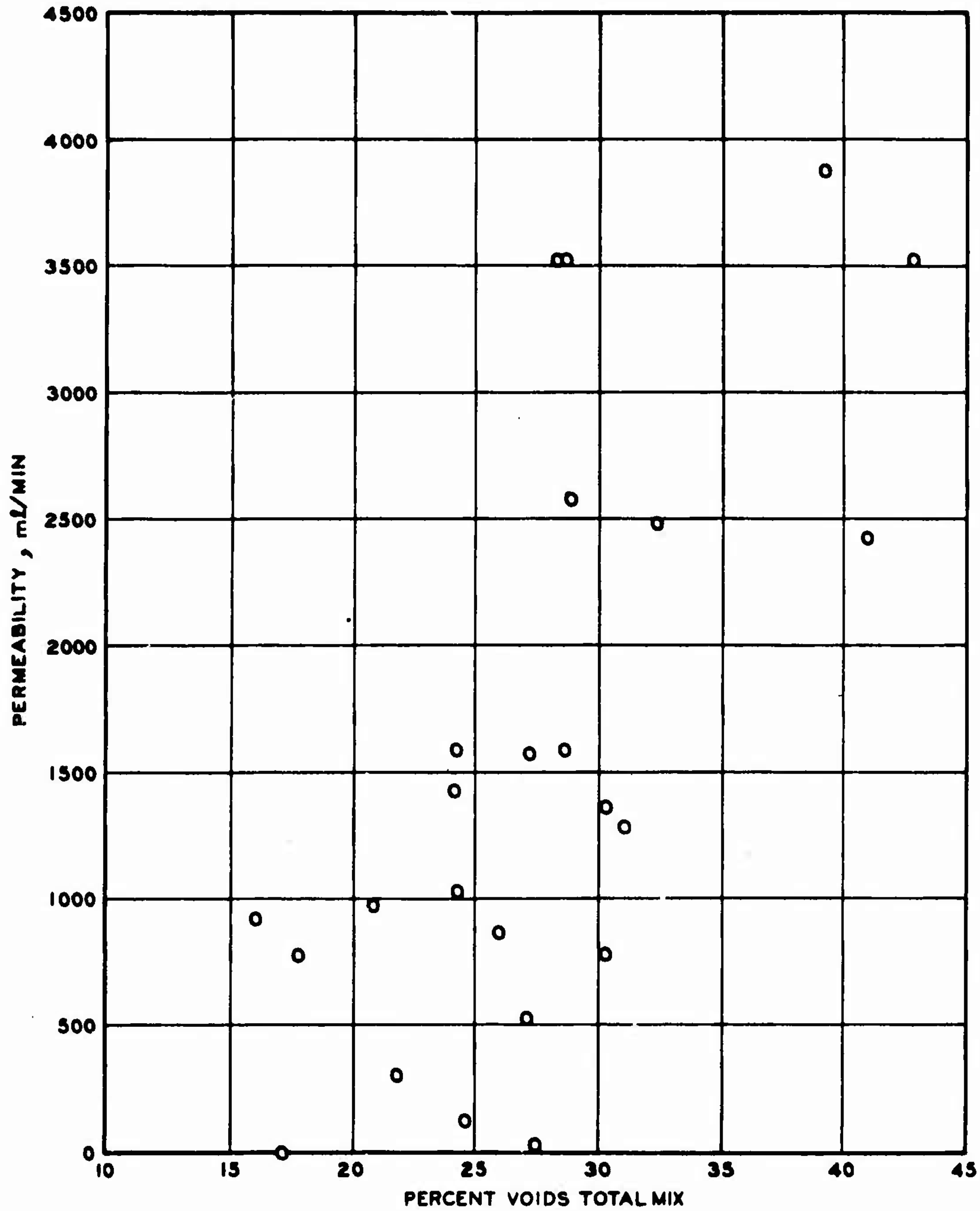


Figure 44. PFC water permeability versus percent voids total mix

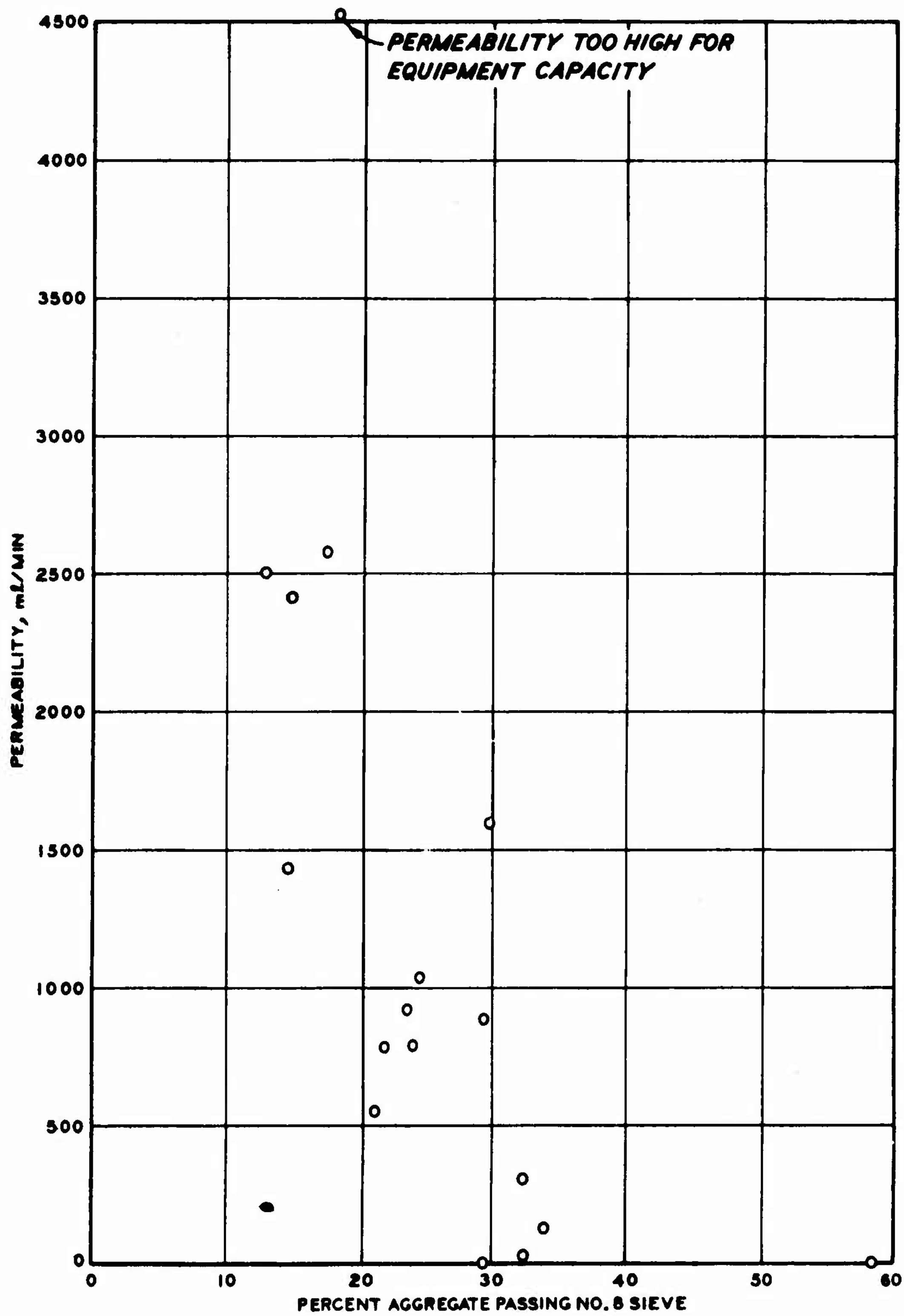


Figure 45. PFC permeability versus percent aggregate passing No. 8 sieve

APPENDIX A: PERMEABILITY TEST

The results of the permeability tests are affected by the surcharge load applied to insure contact of the standpipe and pavement surface. A surcharge load of 100 lb has been satisfactorily used to insure that the conditions of the tests are reasonably constant in this respect. In the field, an open truck door or bumper-mounted bracket can be used for the reaction weight and an extension screw can be used to apply the load. The loading system should include a ball bearing or universal mechanism for self-alignment. In the field where a truck is used to react against, the truck should not be parked broadside to the wind. Wind rocking the truck will cause the load to vary and affect the results.

In the laboratory, good results have been obtained by conducting the test on 6-in.-diam specimens consisting of a 3/4-in. PFC layer compacted by 10 blows of a Marshall hammer with a 6-in.-diam foot. The 3/4-in. layer is compacted on a 6-in.-diam dense bituminous base. A laboratory CBR mold is used to prepare the specimen. The 10-blow compaction effort has been correlated to give permeabilities equivalent to those obtained in the field.

When the standpipe has been positioned and loaded, water is introduced into the standpipe to a level above the 10-in. mark on the side of the standpipe. Addition of water is then stopped, and the time to fall from the 10- to 5-in. level is measured with a stopwatch. This test is repeated three times and the average of the values is computed. The flow rate is determined from the relation $Q = VA$. Thus, for a 5-in. falling head, Q in millilitres per minute is equal to 15,436.8 divided by the time to fall in seconds. A wide range in permeability can be expected to be measured, but a reasonable lower limit of permeability for newly constructed PFC pavements is 1000 ml/min.

APPENDIX B: PFC DESIGN PROCEDURE

The design procedure for PFC pavements consists of primary and validation procedures.

The primary procedure involves conducting the Centrifuge Kerosene Equivalency (CKE) tests on the proposed job aggregate using Test Method California No. 303-F.[9] The K_c value determination from this test is used in the relation $2K_c + 4.0$ to obtain an estimate of asphalt content (EOA). The amount of binder estimated from this relation has been evaluated in the laboratory and in the field and is reasonable. To insure that this amount of asphalt can be prepared in a PFC without excessive drainage, a proper mixing temperature must be selected. This is accomplished by choosing a mixing temperature that will give a viscosity of 275 + 25 centistokes. This can only be accomplished by evaluating the temperature-viscosity relation for the specific job asphalt.

These steps essentially provide the necessary information for selection of the binder content for a PFC mixture. However, only close uniform control of the aggregate gradation will insure that the PFC can be satisfactorily produced and constructed.

An evaluation or validation of the above mix design in the laboratory may include the asphalt drainage test and water permeability test.

The asphalt drainage test has not been proven to be sensitive for all types of aggregates; however, the test may be conducted for background information and to insure that detrimental drainage of asphalt does not occur. The test is conducted by preparing a 300-g sample of the mixture at the design binder content, placing the sample in a 6-in.-diam culture dish, and placing the dish in an oven preset at the mixing temperature selected from the temperature-viscosity relation. The sample is removed from the oven after 2 hr and allowed to cool. The amount of drainage to the bottom of the dish is observed. At this time, over 50 percent coverage is assumed to be excessive. If the binder drainage is excessive, either the mixing temperature or binder content can be reduced.

The water permeability test is conducted on specimens prepared as described in Appendix A. It is suggested that laboratory water permeability tests be used to evaluate gradations and binder contents and mixing temperature. A gradation different from the recommended gradation may greatly affect the permeability. The permeability is also affected by the binder film thickness, which is controlled by the binder volume and mixing temperature. Low permeability may also require an adjustment in the binder content or mixing temperature.

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2. American Society for Testing and Materials, "Standard Method of Test for Measuring Surface Frictional Properties Using the British Portable Tester," Designation: E 303-69, 1973 Annual Book of ASTM Standards, Part 11, 1973, Philadelphia, Pa.

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4. American Society for Testing and Materials, "Standard Method of Test for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures," Designation: D 2172-72, 1973 Annual Book of ASTM Standards, Part 11, 1973, Philadelphia, Pa.

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6. __________, "Standard Method of Test for Penetration of Bituminous Materials," Designation: D 5-73, 1973 Annual Book of ASTM Standards, Part 11, 1973, Philadelphia, Pa.

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8. __________, "Standard Method of Test for Recovery of Asphalt from Solution by Abson Method," Designation: D 1856-69, 1973 Annual Book of ASTM Standards, Part 11, 1973, Philadelphia, Pa.

9. California Division of Highways, "Method of Test for Centrifuge Kerosene Equivalent Including K-Factor," Test Method No. Calif. 303-F, Oct 1974, Sacramento, Calif.